FORECASTING THE MOTION OF NORTHEASTERN PACIFIC TROPICAL CYCLONES

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THESIS

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Northeastern Pacific Tropical Cyclones

by

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ABSTRACT

Several operational methods of forecasting the motion of tropical cyclones over the northeast Pacific Ocean area are evaluated for three 1970 and nine 1971 hurricanes. OFFICIAL forecast accuracy is shown to excel that of TYRACK (1971 only) and HATRACK (both years). The MODIFIED HATRACK (MODHATR) forecast scheme developed by the Navy in Monterey, California, comprising a numerical steering component (HATRACK) and a statistical modification (correction for bias in HATRACK) is applied to the same 1970-71 operational data, with the result that the MODHATR accuracy, using 850-mb steering, is shown to be superior to HATRACK and TYRACK while only slightly inferior to the OFFICIAL forecasts. Specifically, MODHATR forecast accuracy lies in the range 7 to 5 kt for 12 to 72 hour forecasts, respectively, while the ratios of OFFICIAL to MODHATR errors range from 1 to .7 in 1970 for forecasts 12 to 48 hours and from .9 to .8 in 1971 for 12 to 72 hour forecasts, respectively. The number of 1970 forecasts evaluated in the test averaged 35 per forecast interval while the 1971 forecast sample ranged from 160 at 12 hours to 45 at 72 hours.

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I. OBJECTIVES OF THE STUDY

The objectives of the study were as follows:

1. To generally assess the current status of subjective and objective forecasting of tropical cyclone motion in the northeastern Pacific Ocean area.

2. In particular, to determine the applicability of the MODIFIED HATRACK forecast scheme to the movement of such tropical cyclones.

3. To advise Fleet Weather Facility (FWF), Alameda, on the utility of available objective guidance for the 1972 tropical cyclone season.

II. THE AREA OF STUDY

The tropical northeastern Pacific Ocean ranks second, globally, in the production of tropical cyclones of at least storm intensity [Atkinson 1971]. Fig. 1 shows the area of usual occurrence. Climatology shows that the cyclone season begins in May and ends in November, with the peak of activity in August and September. Table 1 illustrates the cyclone activity of the past five years [FWC/JTWC 1971], during which era satellite observations played an important role in detection and tracking.

The tropical northeastern Pacific Ocean is notorious for its sparsity of data, especially in the area of tropical cyclone activity. Fig. 1, illustrative of this fact, shows the fixed reporting stations and a typical distribution of reports from transiting ships. Because of this situation, one of the greatest aids in locating the cyclones has been the daily Automatic Picture Transmission (APT) pictures received via Forecasters Facsimile (FOFAX) [FWC/JTWC 1972]. Such observations supplement limited aircraft reconnaissance of the cyclones.

The importance of the area to the Navy is demonstrated in Table 2 which shows an example of the number, points of origin and destinations of Navy ships and ships under Naval contract which ply the area. Information concerning the number of non-Navy ships is not known but the number of

[illegible]

ships which transit the Panama Canal is in excess of 14,000 [World Almanac 1972] per year some of which evidently pass through part of the tropical northeastern Pacific Ocean.

III. AVAILABLE FORECAST TECHNIQUES

The forecasting of cyclone movement in the tropical northeastern Pacific Ocean area has been a result of objective guidance (e.g., HATRACK and TYRACK, discussed in sections B and C) and subjective reasoning [FWC/JTWC 1972], the latter heavily influenced by climatology and extrapolation [Denney 1971]. However, to this date, the quality of the objective techniques has not been statistically evaluated for the area and, therefore, is of unknown value as forecast guidance. The only forecast statistics published are those of the subjectively-derived OFFICIAL forecasts [FWC/JTWC 1971; 1972].

A. THE OFFICIAL FORECAST

The OFFICIAL forecast stems from a cooperative effort between FWF, Alameda and the National Weather Service Forecast Office, Redwood City, California. As indicated above, the OFFICIAL forecast in the area is largely subjective; objective guidance is minimal at best.

The type and frequency of forecasts for the tropical northeastern Pacific Ocean are much like those issued for the North Atlantic Ocean area (See Fig. 2). Once the cyclone has been designated as a depression, such forecasts are disseminated for the prime intervals 12, 24, 48, and 72 hours, initiated from synoptic-time (0000, 0600, 1200, and 1800GMT) positions.

B. THE TYRACK SCHEME

The TYPHOON TRACKING (TYRACK) scheme was developed by Fleet Weather Central (FWC), Pearl Harbor as a synoptic-statistical approach to forecasting the movement of tropical cyclones. The scheme considers the cyclone center as a point in a field of smoothed, objectively-analyzed, observed winds. If no history on past movements is available or if the history position is dubious, the 700 mb level is arbitrarily chosen as the best steering level. The U and V components of the steering-level wind are calculated at the cyclone center and the cyclone is steered for three hours utilizing these components. At the end of the three-hour interval, a new center position is determined, the U and V components are computed and the cyclone is steered for another three-hour interval. This process is repeated to 48 hours and the 12, 24, 36 and 48 hour forecast positions are determined.

If history positions are available and are considered accurate, the procedure is similar, but the steering level is determined from prior movement. The best steering level is selected by using the U and V components of the wind at the present position to steer the cyclone center back, 12 hours in time, for all six previously-determined levels (i.e., 700 mb, 500 mb, 400 mb, 300 mb, (700+500)/2 and (700+500+400+300)/4). The level whose winds move the cyclone closest to the 12-hour history position is then selected as the best steering level. As before, the center

is steered in three-hour intervals to 48 hours and the 12, 24, 36 and 48 hour forecast positions calculated. TYRACK forecasts, computer generated by FWF, Pearl Harbor, Hawaii, were made available, at synoptic times, to the FWF, Alameda forecaster during the 1971 tropical cyclone season.

Fig. 3 illustrates the information available in the TYRACK forecast. In this example, the name of the cyclone and the time from which all forecasts are made appear in the heading. Hurricane Olivia has been steered from 1200GMT 27 September 1971. The column labeled LEVEL, gives the steering level for the forecast. The POSIT column indicates the forecast interval. The HISTORY position always refers to the position of the cyclone 12 hours prior to start time. The LAT, LONG columns show the forecast positions of the cyclone. Since, in this example, the history position is given, the cyclone was steered back in time and, as can be seen by the last set of forecasts, the 300 mb level steered the storm back closest to the history position and therefore was chosen as the best steering level for the forecast. If a history position was not available, the cyclone would have been steered by the 700 mb level winds.

C. THE HATRACK SCHEME

The HURRICANE AND TYPHOON TRACKING (HATRACK) forecast scheme, developed cooperatively by the Naval Postgraduate School (NPS) and Fleet Numerical Weather Central (FNWC), Monterey, California, is based on the assumption that the

geostrophic wind at some isobaric level above the cyclone center, as derived from FNWC's SR field, is a good measure of the speed and direction of movement of the cyclone center. The SR field is numerically computed by heavily smoothing the height contours of a constant pressure surface. The smoothing operation essentially removes the short wave disturbances, including tropical cyclones, and retains the long wave pattern. Thus, the center of the cyclone is placed in the remaining long wave pattern and the U and V components of the quasi geostrophic wind[1] are computed to steer the cyclone.

The HATRACK forecasts, computed by FNWC, Monterey, each six hours, for forecast intervals to "X" hours (X=72 in 1970 and 84 in 1971) are processed at the request of FWF, Alameda. An example of a HATRACK forecast for hurricane Lorraine is given in Fig. 4. 1800GMT 19 August 1970 (18190870) is the initial time, 14.5N, 112.8W represents the initial position and the forecast set extends to 66 hours, equivalent to 12220870 (i.e., 1200GMT 22 August 1970). 12190870 gives the time and date of the SR analysis and its associated prognoses which were utilized to compute the quasi geostrophic steering components. 1000 mb represents the steering level. The maximum interval of the forecast set is six hours less than "X" due to the

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[1]Quasi refers to the fact that the sine function is adjusted at low latitudes.

six-hour time difference between the SR analysis and the initial position.

During the 1970 season, intermittent HATRACK forecasts to 72 hours were provided to FWF, Alameda, utilizing fields at the three steering levels, 1000, 700, and 500 mb. In 1971 the intervals were extended to 84 hours and the 850 mb level was included. Renard (1968) and Renard, Colgan, Daley and Rinard (1972) have reported on the results of forecast experiments with this technique for the North Atlantic Ocean area.

D. THE MODIFIED HATRACK SCHEME

It has been noted (Renard 1968) that HATRACK forecast paths and best tracks[2] of North Atlantic Ocean cyclones are similar in shape but the positions at coincident times are out of phase. Since this bias is reasonably persistent in time, a simple estimate of it has been used to correct the Atlantic-area HATRACK forecasts, resulting in MODIFIED HATRACK (MODHATR) forecasts which are more accurate than the HATRACK forecasts. Specifically, the approach, as developed, utilizes known six-and twelve-hour errors in the HATRACK forecasts to correct the positions in the remaining intervals, separately by latitudinal and longitudinal components. The computed six-and twelve-hour errors (E) are linearly extrapolated by the following

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[2]Best track refers to the documentary position of the tropical cyclone centers.

formula to generate MODHATR error forecasts to any interval, Δt_n; t_n represents time, in hours.

$$E_{\Delta t_n} = E_{12} + \frac{(E_{12} - E_6)(t_n - 12)}{6} \tag{1}$$

Thus, the estimated HATRACK forecast error at t_n hours is the error at 12 hours plus $[(t_n - 12) / 6]$ times the difference between the six-and twelve-hour HATRACK errors. These estimated errors are then applied as corrections to the HATRACK forecast positions to yield MODHATR forecast position, $F'_{t_n - 12}$.

$$F'_{t_n - 12} = F_{t_n} + E_{\Delta t_n} \quad , \tag{2}$$

where $F'_{t_n - 12}$ is the MODHATR forecast position for a time 12 hours less than t_n, and F_{t_n} is the HATRACK forecast position at t_n. Renard, Daley and Rinard (1970), Colgan (1971) and Renard, Colgan, Daley and Rinard (1972) describe the MODHATR scheme in detail, including certain empirical restrictions employed in its application.

This scheme has not been used operationally in the northeastern Pacific Ocean area to this date. Most of the developmental and operational testing has been confined to the North Atlantic Ocean area but limited to the former until 1971. The following chapter describes the testing procedures applied to the 1970 and 1971 hurricanes of the subject Pacific Ocean area.

IV. TESTING PROCEDURES

The procedure for testing the accuracy of the MODHATR forecast scheme may be outlined as follows. The mean errors are calculated as a function of forecast interval for the OFFICIAL, TYRACK, HATRACK and MODHATR forecast schemes and by comparing objective schemes to OFFICIAL forecasts, the merits of the objective schemes are evaluated.

Since the examination of the two seasons was basically the same, the procedure used in 1970 will be presented and only departures from this procedure will be discussed for the 1971 season.

As stated in Chapter III, all tropical cyclone data were provided by FWF, Alameda. The 1970 data comprised OFFICIAL forecasts including operational positions[3] (Fig. 2), TYRACK forecasts (Fig. 3), intermittent HATRACK forecasts derived from steering at 1000, 700 and 500 mb levels (Fig. 4), and best tracks. The available data were examined and three tropical cyclones (Francesca, Lorraine and Patricia) were selected for preliminary study. Only the cyclones reaching hurricane intensity were selected to enable examination of the objective schemes during all stages of tropical cyclones.

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[3]Operational positions are the best available real-time locations of the cyclones.

The OFFICIAL (12, 24, 48, and 72 hour) forecasts were verified against the best-track positions and error statistics were compiled for each forecast interval. The HATRACK forecasts, begun from the operational positions, were also verified against best-track positions for all forecast intervals. The MODHATR forecasts were computed for all available HATRACK forecast sets using both best-track and operational positions for calculation of the bias correction. The resulting forecast positions were then verified against the best-track positions and the error statistics compiled. For all schemes, the errors are presented in nautical miles per hour, as a normalizing approach to aid in comparing error statistics.

The testing procedure for the 1971 season was the same as that for the 1970 season, but the data were more complete. During the 1971 season, the 850 mb steering level was added to the data set. Extending the HATRACK forecast sets to 84 hours allowed MODHATR forecasts to be calculated to 72 hours.

The HATRACK data for all but two cyclones which reached hurricane intensity (Agatha, Denise, Hilary, Ilsa, Lily, Monica, Nanette, Olivia and Priscilla) were utilized. Bridget and Francene were lost due to computer problems. Also, positions equal to and less than 5N were omitted. Computation of HATRACK forecast positions equal to and less than 5N requires data from the Southern Hemisphere. The HATRACK program was not designed for calculations on

Southern Hemisphere grid points and, therefore, erroneous forecasts are generated. For this reason, the program included an execution step to exclude such forecasts. Further, starting positions of all HATRACK forecasts were compared to the operational cyclone positions and any forecasts which were generated from a position vectorially more than one degree latitude from the operational position were arbitrarily excluded.

The 1971 TYRACK (12, 24, 36, and 48 hour) forecasts were verified against the best track positions and error statistics were compiled.

The difference between the best-track and operational positions for the 1970 and 1971 tracks was examined in an attempt to correlate large forecast errors and large starting errors. No relationship between these parameters could be established.

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V. RESULTS AND ERROR ANALYSIS

The primary objectives of the study were to evaluate the merits of the MODHATR scheme and report these results to FWF, Alameda, for use as objective guidance in the 1972 hurricane season.

As stated in Chapter IV, the HATRACK forecast sets were first modified by the best-track positions of the cyclones. This procedure was carried out to establish the potential accuracy of the MODHATR scheme. The potential accuracy may be regarded as indicative of the optimum performance of the scheme using the best possible positions to calculate the bias corrections. But, since the best-track positions are not compiled until after the completion of the season, they cannot be used in operational real-time. Therefore, to determine the current or actual accuracy, it was necessary to calculate the bias corrections utilizing cyclone positions that would have been available in operational real-time. The following section discusses the MODIFIED HATRACK errors, as a function of both modes of the bias correction and in relation to OFFICIAL and TYRACK forecasts.

A. RESULTS

The error statistics for the 1970 HATRACK forecasts, compared with those for the OFFICIAL forecasts, are presented in Fig. 5. The mean error, in nautical miles per hour of forecast interval, is plotted against the forecast

[illegible]

interval. It is readily seen that the guidance provided by the HATRACK scheme is minimal. For example, the mean error in the 12 hour OFFICIAL forecast is 5.8 kt or 69.6 n mi, while on the average, the minimum HATRACK errors are achieved utilizing 700 mb steering with a value of 6.2 kt or 74.4 n mi, with larger differences between the two methods in the longer forecast intervals.

By comparing the mean errors, in each forecast interval, between the OFFICIAL and objective forecasts and expressing the result as an error ratio, the relative accuracy of the two methods is established. If only those forecasts which exhibit a one-to-one correspondence (i.e., equivalent forecast intervals and valid at the same synoptic time) are compared, a homogeneous sample results. A non-homogeneous sample comprises all OFFICIAL forecasts and all objective forecasts of the same forecast interval. Figs. 6 and 7 show the results of the two comparisons between the OFFICIAL and HATRACK errors. It should be noted that the error ratio is always less than one (i.e., OFFICIAL always less than HATRACK mean errors) and decreases in the longer forecast intervals.)

Figure 8 illustrates the mean error results for MODHATR (best-track) bias forecasts. As previously stated, use of best-track bias establishes a potential accuracy which, is greater than that of the OFFICIAL forecast through 48 hours when the optimum steering level (700 mb) is utilized. Figs. 9 and 10 are similar to Figs. 6 and 7 except that

the MODHATR (best-track bias) results show that the potential accuracy of this scheme is greater than that of the OFFICIAL forecasts for the 12 and 24 hour intervals. The trend of decreasing accuracy in longer forecast intervals remains.

The best steering level for the objective schemes is obvious from Figs. 6 through 10. The 700 mb steering level gives the most accurate results in all cases.

The state-of-the-art accuracy was determined by producing MODHATR forecasts utilizing operational positions to calculate the bias. A comparison of the MODHATR (operational bias) forecasts to the best-track positions gives a measure of its expected performance under operational conditions. Since the previously stated results clearly show that the 700 mb steering produced the most accurate forecasts, MODHATR (operational bias) forecasts were calculated only for HATRACK forecasts resulting from 700 mb steering. The results of the mean error calculations are shown in Fig. 11. It should be noted that not only is the overall deterioration of the scheme evident but that the deterioration is much more severe in the shorter forecast intervals (i.e., less than 36 hours). It should also be noted that the MODHATR (operational bias) forecasts are overall better than those of the HATRACK scheme. The error ratios of Figs. 12 and 13 show that the MODHATR (operational bias) accuracy is inferior to that of OFFICIAL whether the sample is homogeneous or non-homogeneous.

The 1971 results are presented in Figs. 14 through 23 utilizing the 1970 format. Fig. 14 shows the HATRACK errors for the 1971 cyclones. Comparison to Fig. 5 shows extended forecast intervals, the addition of the 850 mb steering level and overall similarity of patterns. The extended forecast intervals were discussed in Chapter IV. Figs. 15 and 16 give error ratios at all steering levels for a homogeneous and non-homogeneous sample, respectively. The similarities to Figs. 9 and 10 are evident but the ratios are greater throughout, probably a result of favorable changes to the FNWC prognostic program. Fig. 17 illustrates the potential accuracy of MODHATR (i.e., best-track bias) utilizing the 1971 data. It is evident that the 850 mb steering results are more accurate than those for 700 mb. Comparison to Fig. 8 reveals that although the basic pattern of increasing error with increasing forecast interval persists, the point at which the 850 MODHATR (best-track bias) forecasts become poorer than OFFICIAL has been extended to 60 hours. This increased accuracy is also reflected in the homogeneous and non-homogeneous comparisons with OFFICIAL (shown in Figs. 18 and 19) by error-ratio values greater than one through the 48 hour forecast intervals.

The operational performance of the MODHATR scheme was determined as in 1970. The mean-error results are given in Fig. 20 where they may be compared to the best-level HATRACK errors. Comparison to Fig. 11 shows that the two

sets of results are of the same basic pattern, but again, the 1971 MODHATR (operational bias) errors are closer to the OFFICIAL errors especially in the longer forecast intervals. The error ratios of Figs. 21 and 22 point out that even though the 1971 MODHATR (operational bias) results are better than the 1970 results, the OFFICIAL forecasts are best at all intervals coevaluated.

The error statistics for the TYRACK scheme were tabulated in the same manner as those for the other objective schemes. The TYRACK forecasts were divided into history and no-history categories. These two forecast sets were separated because of the known erratic nature of the initial (operational) positions. It has been the experience of FWC, Pearl Harbor,[4] that the TYRACK scheme is extremely sensitive to errors in the starting positions. This sensitivity was documented when errors of the history forecasts were determined to be greater than those of the no-history forecasts. The no-history errors (700 mb steering) are presented in Fig. 23 where they are compared to both the OFFICIAL and MODHATR (operational bias) in a homogeneous sample. Fig. 23 illustrates that both OFFICIAL and MODHATR (operational bias) forecasts are superior to the best TYRACK forecasts.

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[4]Personal communication with Lt. Gray, FWC, Pearl Harbor.

B. ERROR ANALYSIS

Since the difference between the MODHATR (best-track bias) and the MODHATR (operational bias) schemes is essentially due to the positions utilized for bias determination, therein must lie the answers to the deterioration of the scheme using operational, real-time data.

The most accurate location of a tropical cyclone is provided by a reconnaissance aircraft observation. During the 1970 season, reconnaissance responsibility was shared by the U.S. Navy and the U.S. Air Force, resulting in one near-synoptic time observation per day. 1971 saw the U.S. Air Force assume full responsibility for fixing cyclone positions. In both years, the operational schedule called for a daily, 1800GMT, reconnaissance of northeastern Pacific tropical cyclones, commencing upon designation of the system as a tropical depression. A review of the annual end-of-the-season report shows that in a great majority of the cases, these reconnaissance positions were accepted as both the operational <u>and</u> best track positions of the cyclones.

Figure 24 illustrates the best track and the operational track of hurricane Lorraine, 1970. An examination of these tracks points out both the erratic nature of the operational track and the heavy reliance on reconnaissance positions. This reliance produces large cyclic discontinuities in the operational track which are the result of relocating the 1800GMT cyclone position to agree with the

latest fix. In Fig. 24, two obvious relocations are evident at 1800GMT on 19 and 25 August 1970.

The initial or start time of a HATRACK forecast set is that time from which the forecasts are generated. The MODHATR (operational bias) forecasts were grouped by these associated initial times in an attempt to establish the effect of the track discontinuity between 1200 and 1800GMT. Table 3 gives the mean error (in n mi) as a function of start times. In any forecast interval, a comparison of the mean errors enables an accuracy ranking of the initial times, i.e., from most to least accurate. The results of this procedure are illustrated in Table 4. It is readily seen that from the 1970 data, the 1800GMT start time emerges as the optimum time with 1200GMT as second best. In 1971, the 1200GMT initial times are best with 1800GMT a close second. Therefore, MODHATR forecasts derived from HATRACK forecasts initialized at 1200 or 1800GMT were selected as optimum.

It is believed that the poor performance of the 0000GMT starting time is attributable to the modifying (operational) positions being furthest removed in time, (i.e., 12 and 18 hours) from the last aircraft fix. The poor performance of the 0600GMT initial time is illustrated in Fig. 25. The apparent large, southwesterly movement of the cyclone between the first (1200GMT) and second (1800GMT) modifying positions is utilized by the computer to calculate the bias correction. Since the motion is spurious from

1200-1800GMT, being mostly due to relocation at 1800GMT, the correction is of a similar nature and the resulting MODHATR forecast, in this case, is worse than HATRACK. The forecast generated from best-track bias is shown for comparison. A small number of such situations have a disasterous effect on the forecasts initialized at 0600GMT.

The optimum set of forecasts, those having 1200 and 1800GMT start times, were then compared to the OFFICIAL forecasts. The results for the 1970 data are shown in Fig. 26. It should be noted that the mean error of the MODHATR (operational bias) has been decreased but the OFFICIAL forecast remains superior at all forecast intervals. Fig. 27 shows results for the 1971 data. The MODHATR (operational bias) mean errors are less than or equal to the OFFICIAL errors for forecast intervals through 24 hours. The 1971 result is regarded as more significant due to number of forecasts and the prognostic model in use at FNWC.

VI. CONCLUSIONS

The following conclusions were drawn from this study:

1. The MODHATR forecast scheme is most accurate when using 850 mb in preference to 1000, 700, or 500 mb steering.

2. In general, the MODHATR (operational bias) scheme using 850 mb steering, produces forecasts only slightly inferior to OFFICIAL forecasts. For those MODHATR forecasts derived from steering initiated at 1200 and 1800GMT, the accuracy is equivalent to or superior to the OFFICIAL forecasts through 24 hours in the 1971 sample.

3. The MODHATR skill excels that of TYRACK and thus the former is the best objective scheme available.

4. The major error inherent in MODHATR (operational bias) forecasts originates from the error in operational positions of the tropical cyclone.

5. Further study in the areas of level selection and adjustment of the empirical limits is indicated.

	1967	1968	1969	1970	1971
TOTAL NUMBER OF WARNINGS	474	531	219	350	410
CALENDAR DAYS OF WARNINGS	119	126	67	98	89
TROPICAL DEPRESSIONS	2	6	5	3	3
TROPICAL STORMS	12	13	6	15	8
HURRICANES	6	6	4	3	11
TOTAL	20	25	15	21	22

TABLE 1 A tabulation of the tropical cyclone activity in the northeastern tropical Pacific Ocean, 1967-71. [FWC/JTWC 1971]

PORTS	EASTBOUND	WESTBOUND
CALIFORNIA-CANAL ZONE	30	16
CANAL ZONE-JAPAN, KOREA, TAIWAN, OKINAWA	108	32
CANAL ZONE-SOUTH CHINA SEA	132	210
CANAL ZONE-GUAM	9	10
CANAL ZONE-HAWAII	10	28
SUB-TOTALS	289	296
TOTAL	585	

TABLE 2 A tabulation of the number of ships, either Navy or Naval contract vessels, transiting the northeastern tropical Pacific Ocean during 1970.

FORECAST INTERVAL AND SAMPLE TYPE	0000GMT		0600GMT		1200GMT		1800GMT	
	1970	1971	1970	1971	1970	1971	1970	1971
12 HOUR HOMOGENEOUS	70.4	95.9	75.7	84.7	64.9	62.6	72.9	86.7
12 HOUR NON-HOMOGENEOUS	72.0	91.4	85.5	88.4	64.9	65.6	72.9	84.0
24 HOUR HOMOGENEOUS	138.9	144.9	154.2	158.5	119.2	110.2	118.4	131.0
24 HOUR NON-HOMOGENEOUS	138.9	141.1	154.2	158.5	119.2	109.6	118.4	126.4
48 HOUR HOMOGENEOUS	240.2	248.8	251.9	234.6	232.8	216.4	199.8	254.6
48 HOUR NON-HOMOGENEOUS	240.7	236.9	251.9	231.3	232.8	213.9	199.8	242.5
72 HOUR HOMOGENEOUS		390.6		389.8		407.1		420.4
72 HOUR NON-HOMOGENEOUS		405.4		396.2		385.0		393.6

TABLE 3 The mean error (n mi) in MODHATR as a function of initial times for those forecast intervals common to OFFICIAL and MODHATR.

ACCURACY	1970	NUMBER OF OCCURRENCES	1971	NUMBER OF OCCURRENCES
LEAST MEAN ERROR IN ANY FORECAST INTERVAL	0000GMT	0	0000GMT	0
	0600GMT	0	0600GMT	0
	1200GMT	1	1200GMT	4
	1800GMT	2	1800GMT	0
SECOND BEST FORECAST IN ANY FORECAST INTERVAL	0000GMT	1	0000GMT	0
	0600GMT	0	0600GMT	1
	1200GMT	2	1200GMT	0
	1800GMT	0	1800GMT	3
THIRD BEST FORECAST IN ANY FORECAST INTERVAL	0000GMT	2	0000GMT	2
	0600GMT	0	0600GMT	2
	1200GMT	0	1200GMT	0
	1800GMT	1	1800GMT	0
LARGEST MEAN ERROR IN ANY FORECAST INTERVAL	0000GMT	0	0000GMT	2
	0600GMT	3	0600GMT	1
	1200GMT	0	1200GMT	0
	1800GMT	0	1800GMT	1

TABLE 4 Accuracy of MODHATR (operational bias) forecasts as a function of initial time (see Table 3). Forecasts of 12, 24, and 48 hours are considered in the 1970 sample; forecasts of 12, 24, 48 and 72 are ranked in the 1971 sample.

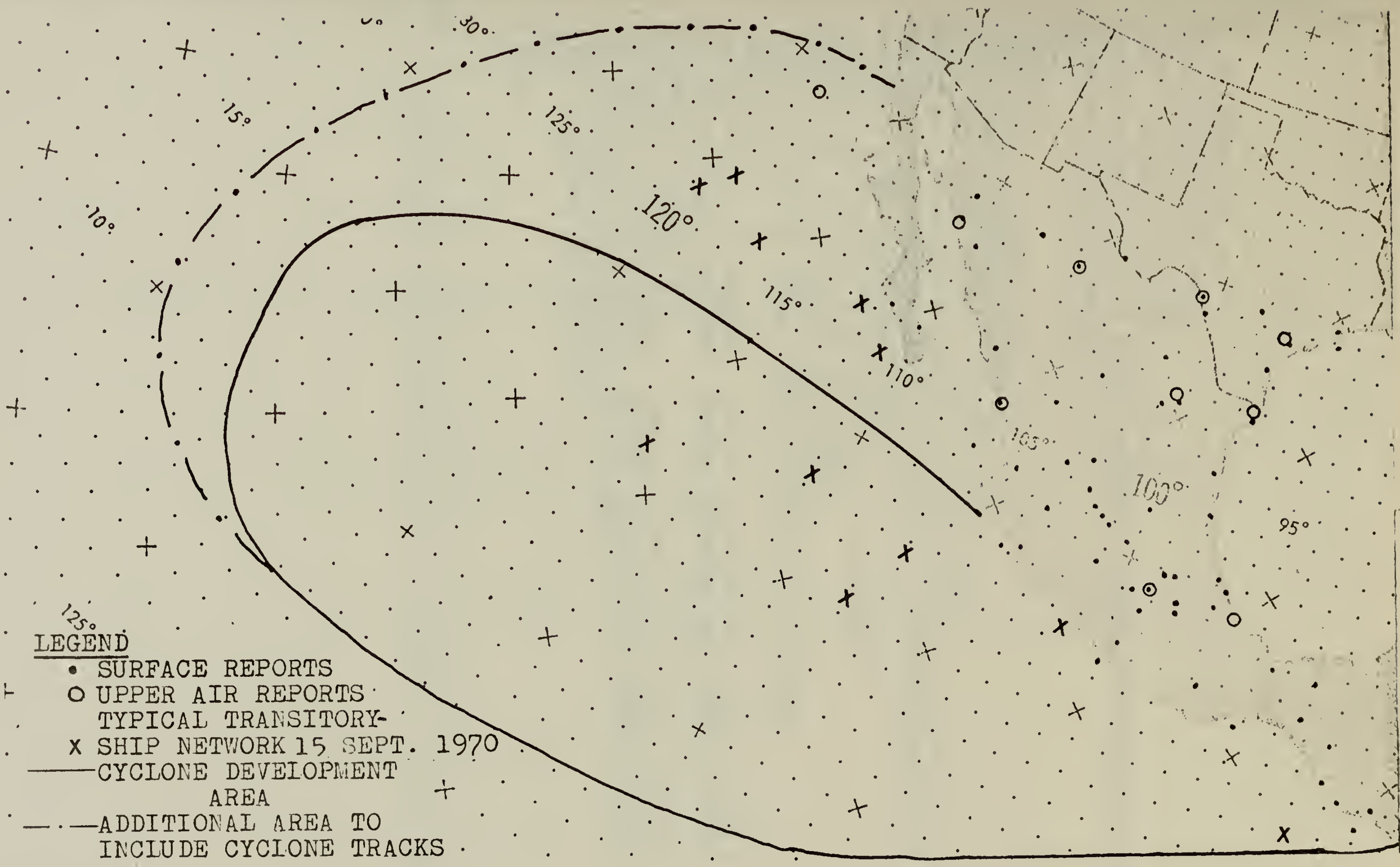

Figure 1 Area of tropical cyclone activity in northeastern Pacific Ocean, with fixed and transitory surface and upper air observation networks. [Atkinson 1971, Sergio 1971]

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O 071450Z JUL 71
FM FLEWEACEN ALAMEDA
TO AIG ONE THREE ONE
INFO RUWJMUA/FLEWEAFAC SDIEGO
RBDIDW/CINC WESTERN FLEET WEATHER CENTRE, NORTHWOOD ENGLAND
RUWTAWA/CARSWELL ADWS
BT
UNCLAS
WHPA KNGZ 071200Z
HURRICANE DENISE WARNING 12
POSITION NEAR 13PT0N 119PT6W AT 071200Z
POSITION ACCURATE WITHIN 70 MILES BASED ON EXTRAPOLATION
PRESENT MOVEMENT TOWARDS THE WEST OR 270 DEGREES AT 10 KNOTS.
PRESENT WIND DISTRIBUTION:
MAXIMUM SUSTAINED WINDS 70 KTS NEAR CENTER
RADIUS OF 50 KT WINDS 40 MILES
RADIUS OF 30 KT WINDS 100 MILES
REPEAT POSITION NEAR 13PT0N 119PT6W AT 071200Z
FORECASTS:
12 HOURS VALID 080000Z 12PT8N 121PT6W MAX WINDS 70 KTS
24 HOURS VALID 081200Z 12PT6N 123PT6W MAX WINDS 70 KTS
EXTENDED OUTLOOK:
48 HOURS VALID 091200Z 12PT2N 127PT5W MAX WINDS 50 KTS
72 HOURS VALID 101200Z 11PT8N 131PT3W MAX WINDS 35 KTS
RECON FLIGHT REQUESTED FOR 071800Z
NEXT WARNING AT 072100Z
BT
 0579
```

Figure 2 Hurricane warning and OFFICIAL forecast for Denise, initiated from 13.0N 119.6W at 1200GMT 07 July 1971.

P 271755Z SEP 71
FM FLEWEACEN PEARL
TO RUWMHLA/FLEWEACEN ALAMEDA
BT
UNCLAS //N03145//
TYRACK FOR HURRICANE OLIVIA FROM 271200Z

LEVEL	POSIT	LAT	LONG
	HISTORY	19.9N	110.2W
700	0	21.0N	111.0W
700	12	24.0N	113.6W
700	24	26.7N	114.9W
700	36	30.9N	113.7W
700	48	37.4N	109.7W
LEVEL	POSIT	LAT	LONG
	HISTORY	19.9N	110.2W
500	0	21.0N	111.0W
500	12	23.1N	112.7W
500	24	25.4N	113.4W
500	36	28.9N	111.7W
500	48	34.6N	106.7W
LEVEL	POSIT	LAT	LONG
	HISTORY	19.9N	110.2W
400	0	21.0N	111.0W
400	12	22.7N	112.3W
400	24	24.8N	112.6W
400	36	28.0N	111.0W
400	48	32.9N	106.2W
LEVEL	POSIT	LAT	LONG
	HISTORY	19.9N	110.2W
300	0	21.0N	111.0W
300	12	22.2N	111.5W
300	24	23.8N	111.2W
300	36	25.7N	109.9W
300	48	27..6N	107.3W
LEVEL	POSIT	LAT	LONG
	HISTORY	19.9N	110.2W
AVG 1	0	21.0N	111.0W
AVG 1	12	23.5N	113.1W
AVG 1	24	26.0N	114.2W
AVG 1	36	30.1N	112.2W
AVG 1	48	36.6N	107.2W
LEVEL	POSIT	LAT	LONG
	HISTORY	19.9N	110.2W
AVG2	0	21.0N	111.0W
AVG2	12	22.9N	112.6W
AVG2	24	25.3N	112.9W
AVG2	36	29.1N	112.8W
AVG2	48	34.4N	105.5W

TYRACK SELECTS 300 AS BEST STEERING LEVEL

LEVEL	POSIT	LAT	LONG
	HISTORY	19.9N	110.2W
300	0	21.0N	111.0W
300	12	22.2N	111.5W
300	24	23.8N	111.2W
300	36	25.7N	109.9W
300	48	27.6N	107.3W

Figure 3 Sample TYRACK forecast for hurricane Olivia, initiated from 21.0N, 111.0 W at 1200GMT 27 September 1971.

```
FM FNWF MONTEREY

TO FWC ALAMEDA

TROPICAL CYCLONE STEERING

EXPERIMENTAL     PROG

A09 LORR

ANAL TIME    12190870

LEVEL    1000 MBS

18190870      145N 1128W   2909

00200870      146N 1139W   2709

06200870      146N 1151W   2611

12200870      144N 1163W   2613

18200870      141N 1177W   2513

00210870      136N 1191W   2413

06210870      129N 1204W   2413

12210870      122N 1216W   2311

18210870      114N 1225W   2311

00220870      106N 1233W   2209

06220870      097N 1239W   2109

12220870      088N 1242W   1908
```

Figure 4 Sample HATRACK forecast for hurricane Lorraine, initiated from 14.5N, 112.8W at 1800GMT 19 August 1970.

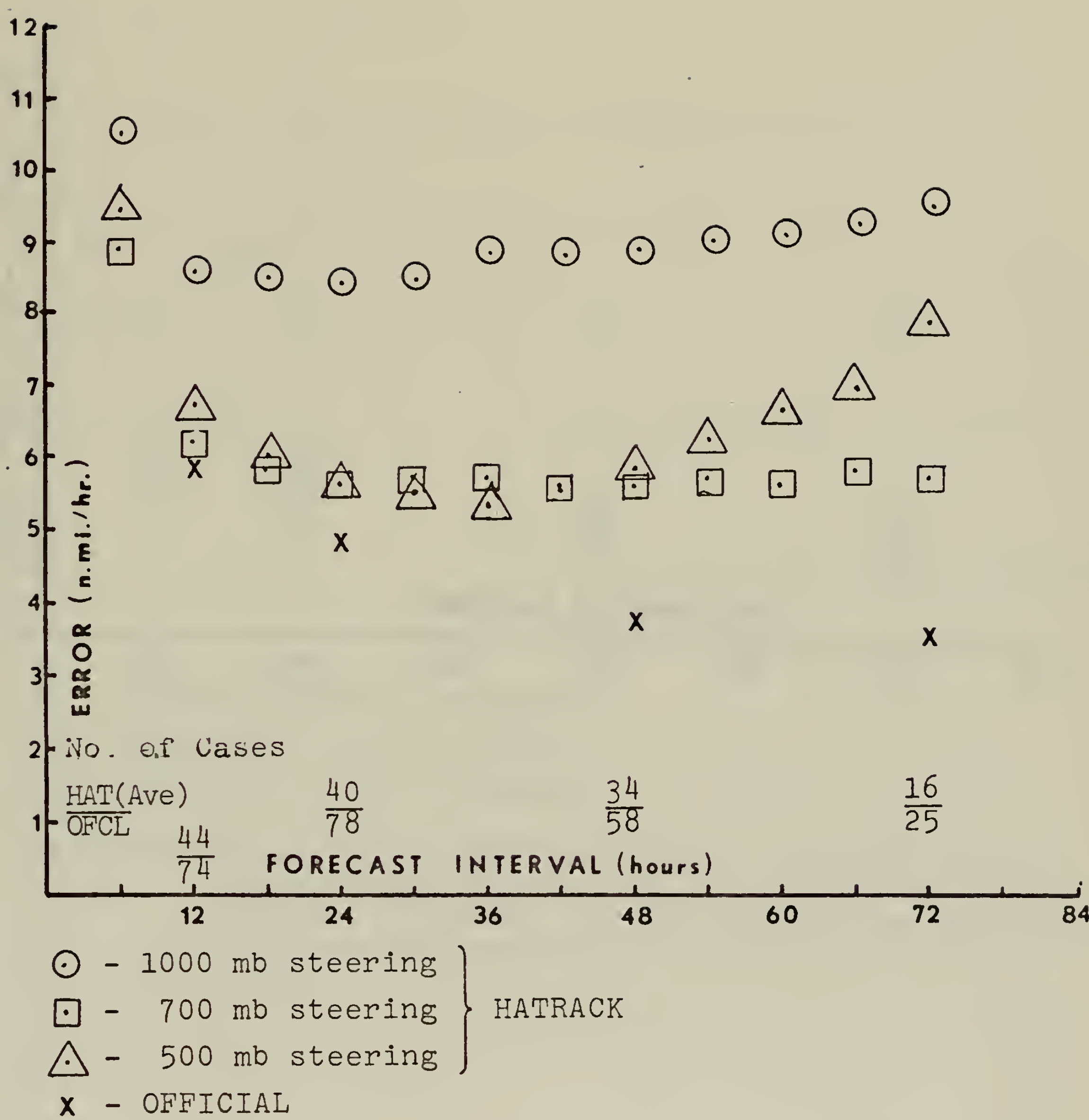


Figure 5 The mean errors of HATRACK and OFFICIAL, as a function of forecast interval for 1970 hurricanes Francesca, Lorraine and Patricia.

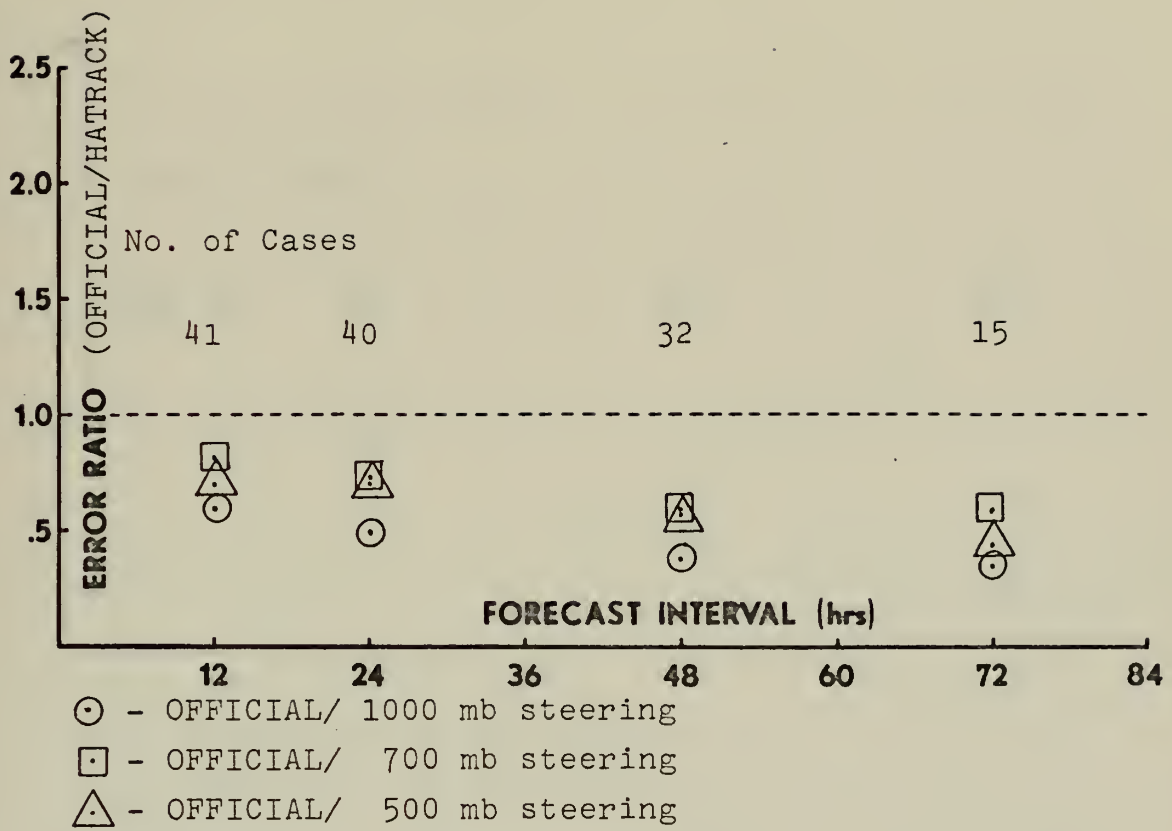
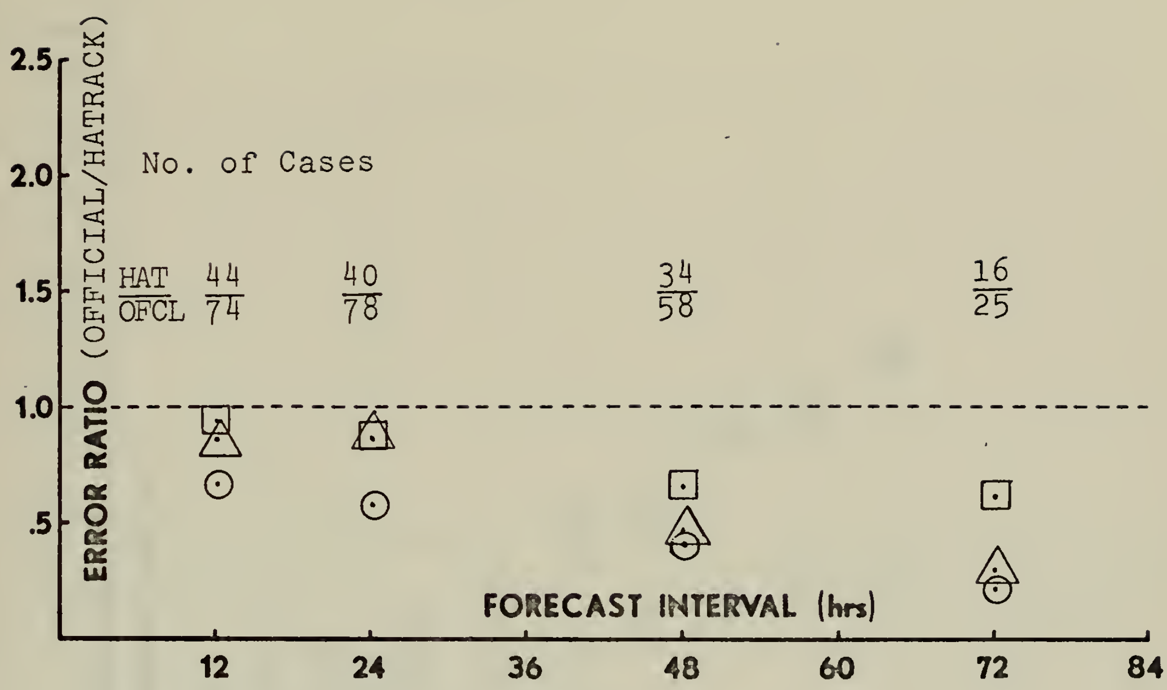


Figure 6 The ratio of OFFICIAL/HATRACK forecast errors, for a homogeneous sample, as a function of forecast interval, for 1970 hurricanes Francesca, Lorraine and Patricia.

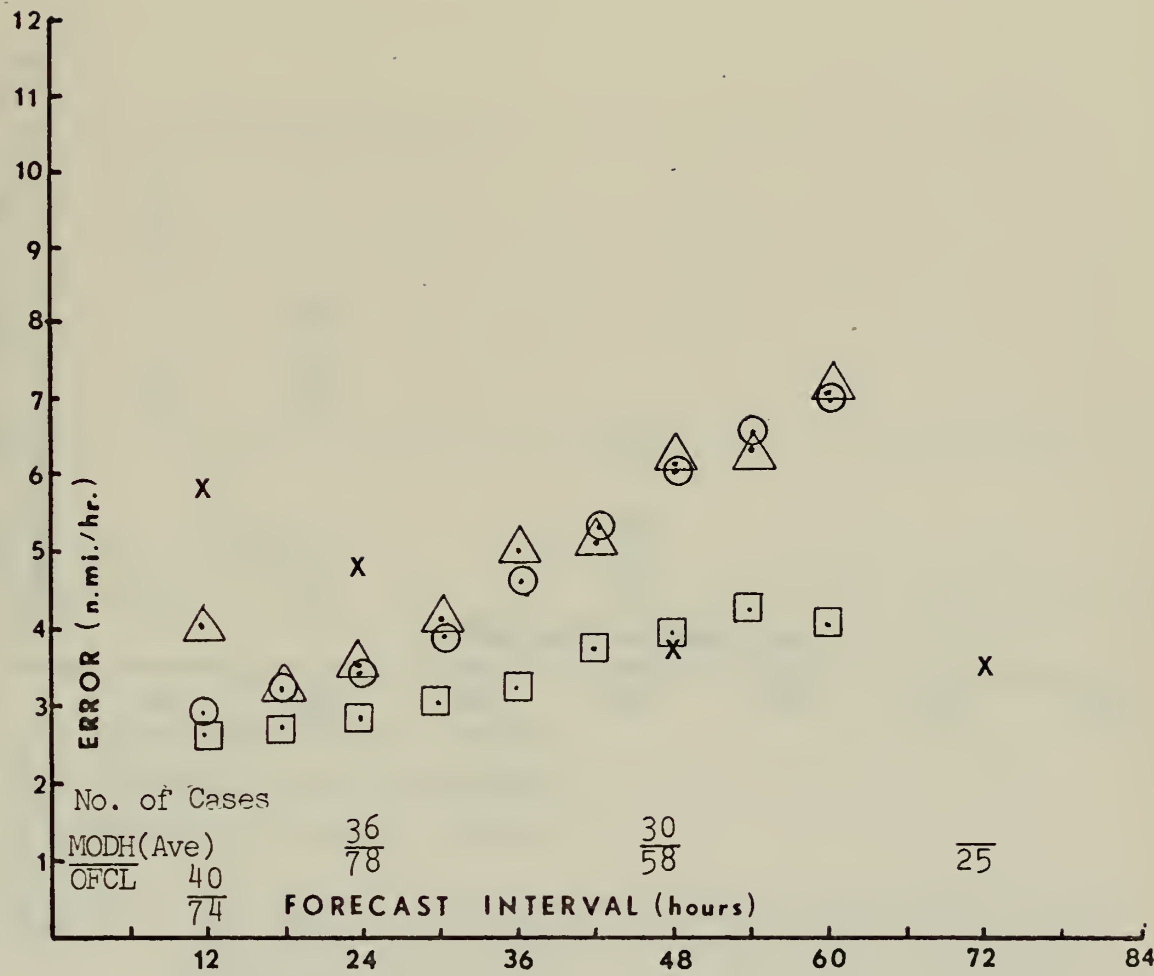


⊙ - OFFICIAL/ 1000 mb steering

⊡ - OFFICIAL/ 700 mb steering

△ - OFFICIAL/ 500 mb steering

Figure 7 The ratio of OFFICIAL/HATRACK forecast errors, for a non-homogeneous sample, as a function of forecast interval, for 1970 hurricanes Francesca, Lorraine and Patricia.



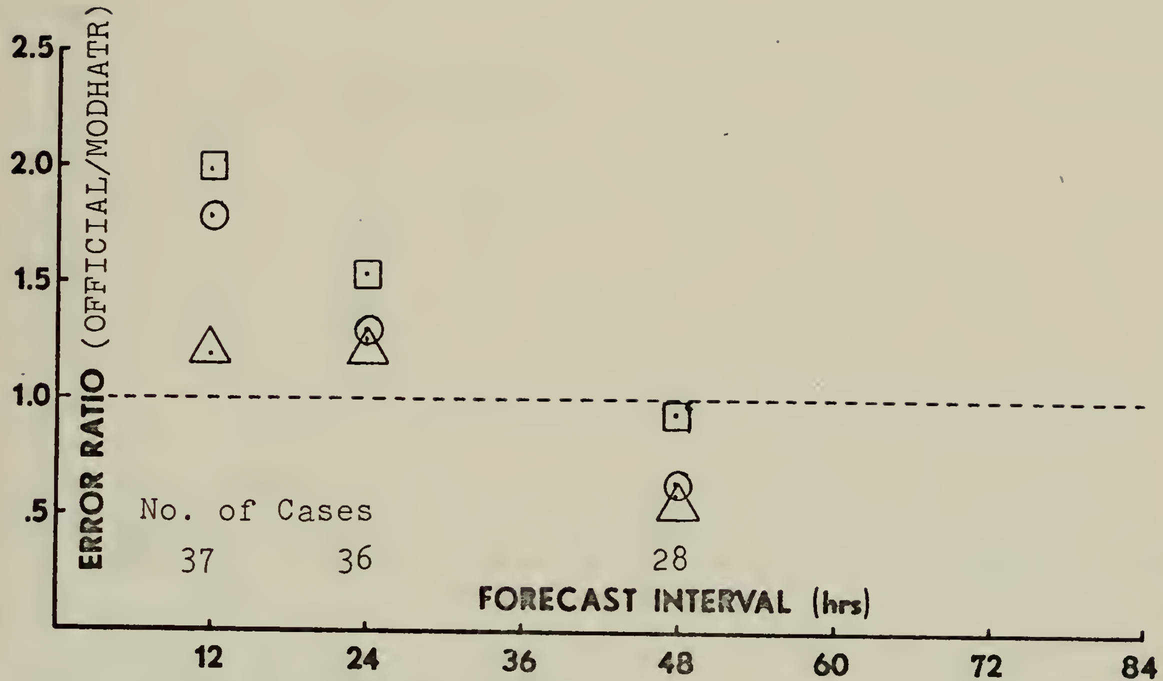
⊙ - 1000 mb steering

⊡ - 700 mb steering

△ - 500 mb steering

X - OFFICIAL

Figure 8 The mean errors of MODHATR (best-track bias) and OFFICIAL, as a function of forecast interval, for 1970 hurricanes Francesca, Lorraine and Patricia.

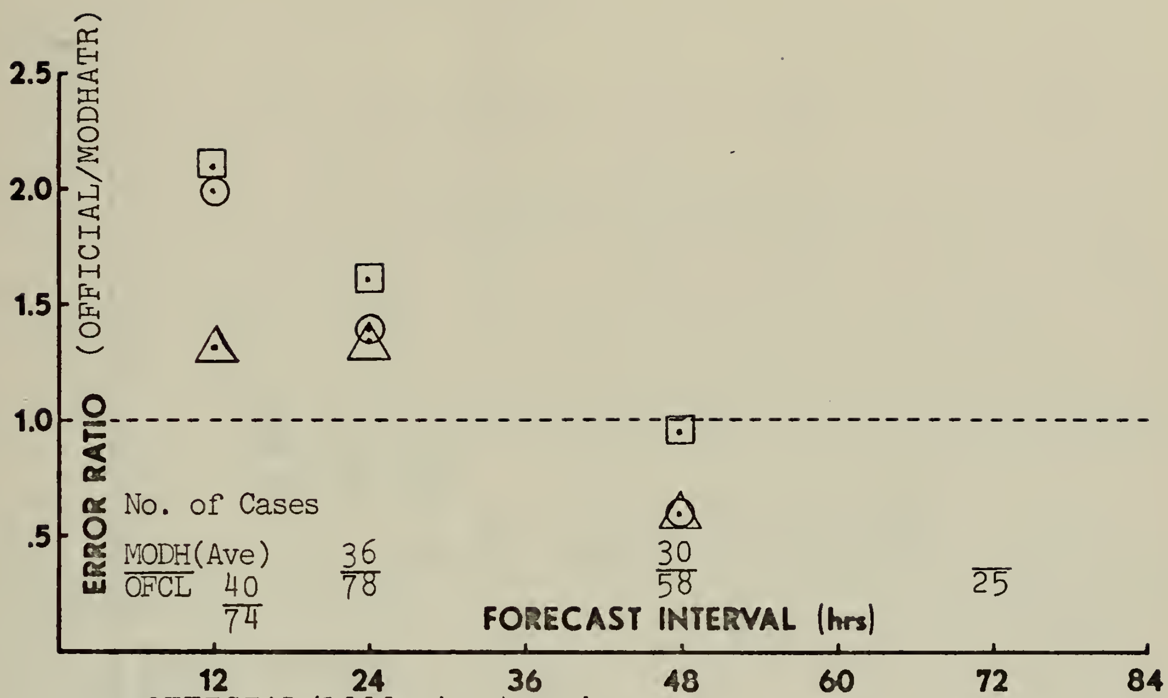


⊙ - OFFICIAL/1000 mb MODHATR

⊡ - OFFICIAL/ 700 mb MODHATR

△ - OFFICIAL/ 500 mb MODHATR

Figure 9 The ratio of OFFICIAL/MODHATR (best-track bias) forecast errors, for a homogeneous sample, as a function of forecast interval, for 1970 hurricanes Francesca, Lorraine and Patricia.



⊙ - OFFICIAL/1000 mb steering

⊡ - OFFICIAL/ 700 mb steering

△ - OFFICIAL/ 500 mb steering

Figure 10 The ratio of OFFICIAL/MODHATR (best-track bias) forecast errors for a non-homogeneous sample, as a function of forecast interval, for 1970 hurricanes Francesca, Lorraine and Patricia.

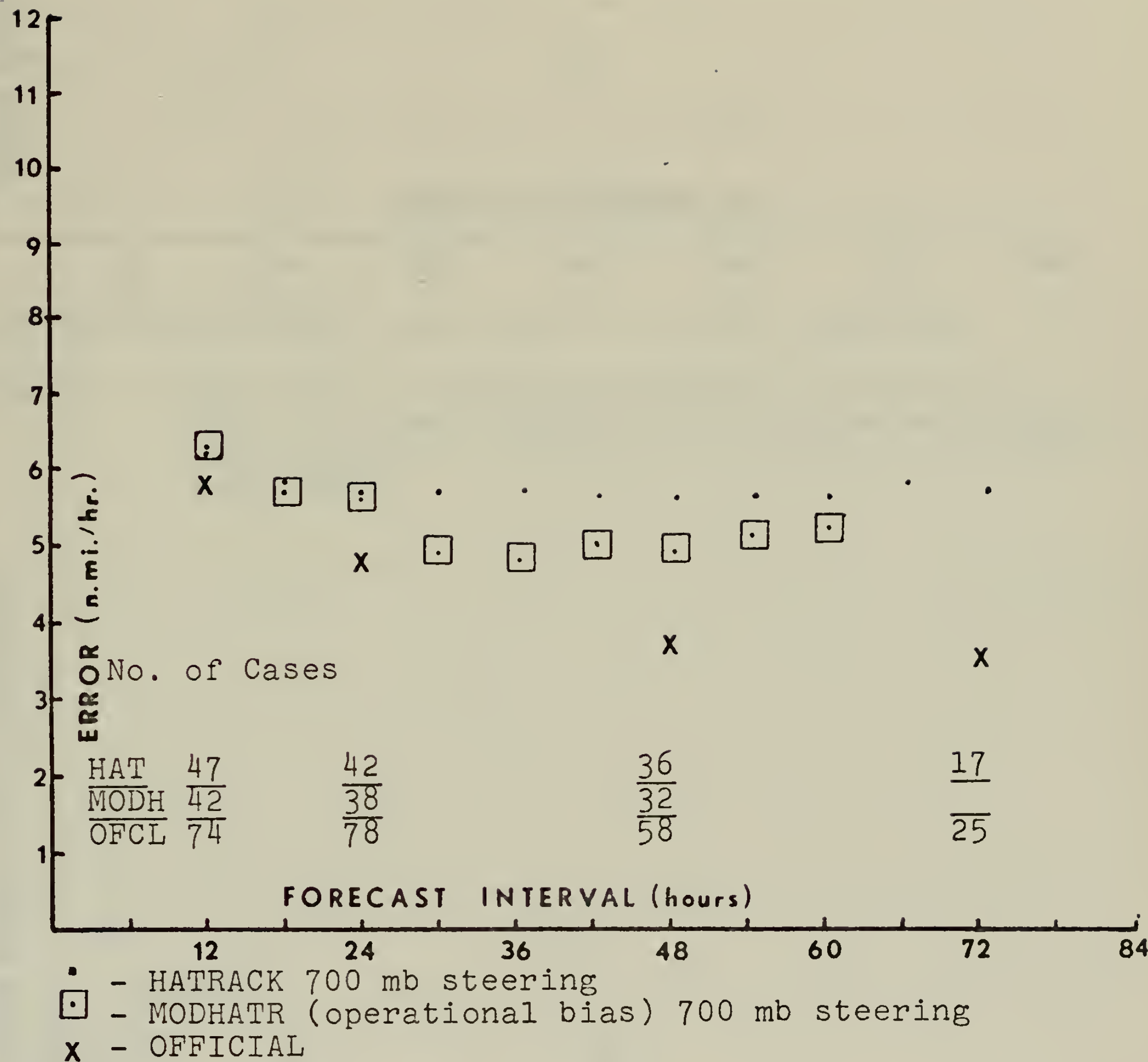
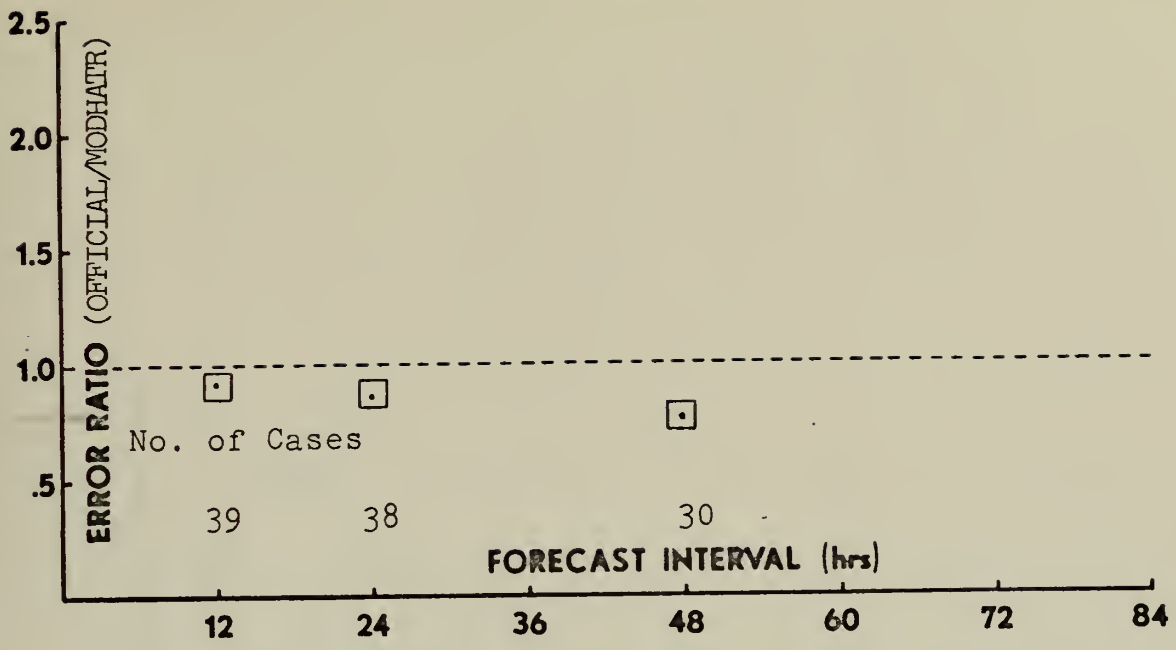
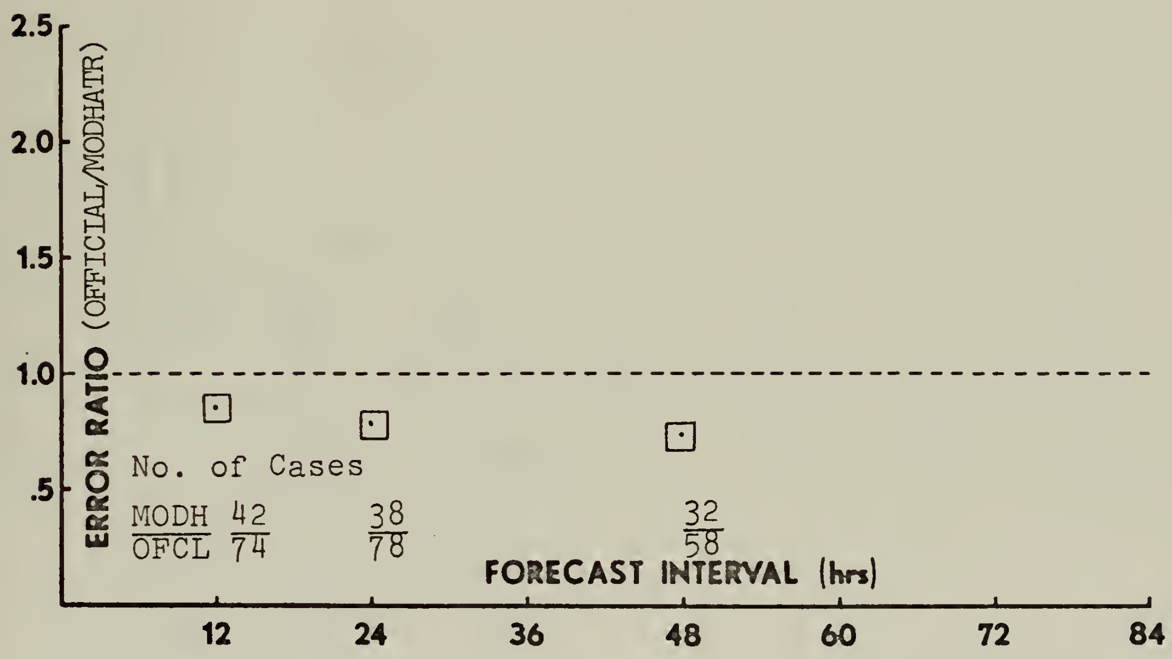


Figure 11 The mean errors of HATRACK (700 mb steering), MODHATR (700 mb steering) and OFFICIAL forecasts, as a function of forecast interval, for 1970 hurricane sample.



⊡ - OFFICIAL/MODHATR Best Level (700 mb) steering

Figure 12 The ratio of OFFICIAL/MODHATR (operational bias) forecast errors, for a homogeneous sample, as a function of forecast interval, for 1970 hurricanes.



⊡ - OFFICIAL/MODHATR Best Level (700 mb) steering

Figure 13 Similar to Fig. 12 except for a non-homogeneous sample.

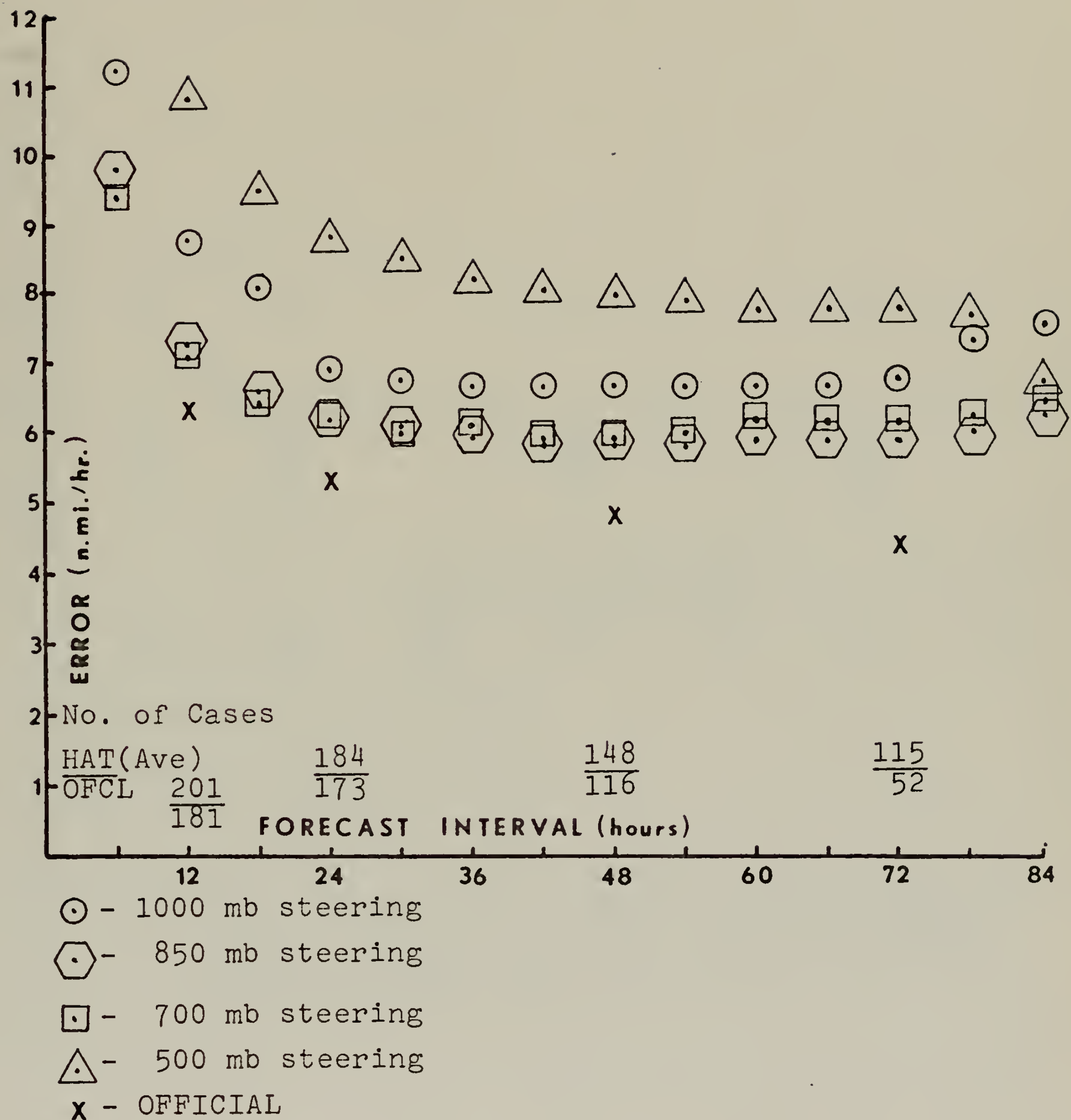
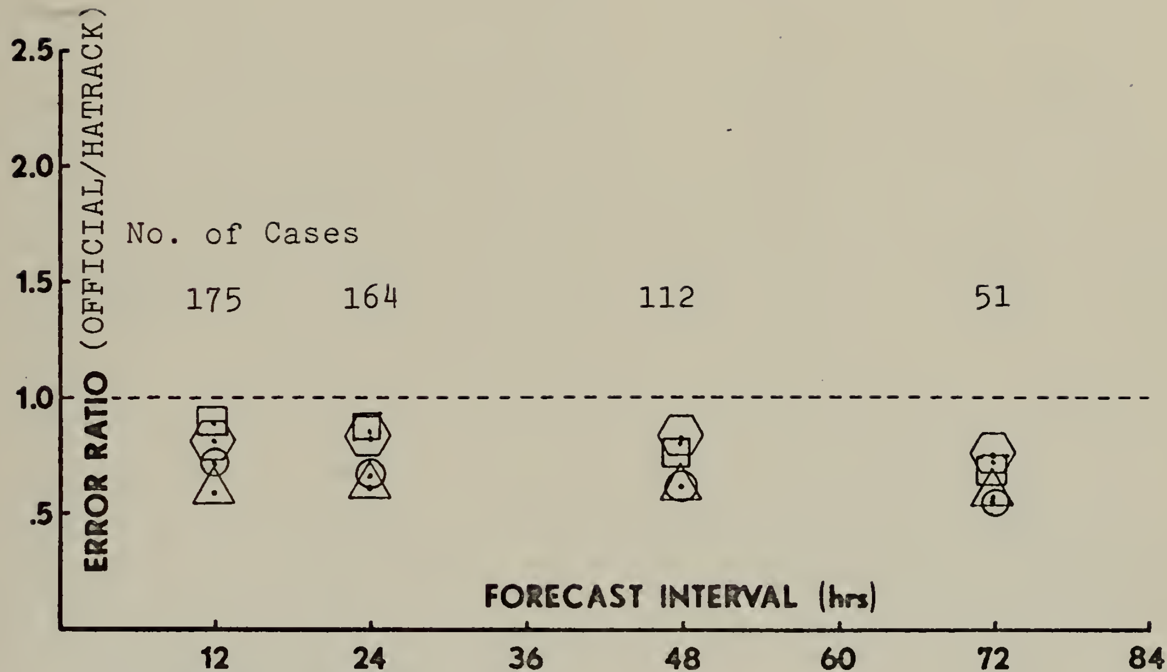


Figure 14 The mean errors of HATRACK and OFFICIAL, as a function of forecast interval, for 1971 hurricanes Agatha, Denise, Hilary, Ilsa, Lily, Monica, Nanette, Olivia and Priscilla.



⊙ - OFFICIAL/1000 mb steering

⬡ - OFFICIAL/ 850 mb steering

⊡ - OFFICIAL/ 700 mb steering

△ - OFFICIAL/ 500 mb steering

Figure 15 The ratio of OFFICIAL/HATRACK forecast errors, for a homogeneous sample, as a function of forecast interval, for 1971 hurricanes Agatha, Denise, Hilary, Ilsa, Lily, Monica, Nanette, Olivia and Priscilla.

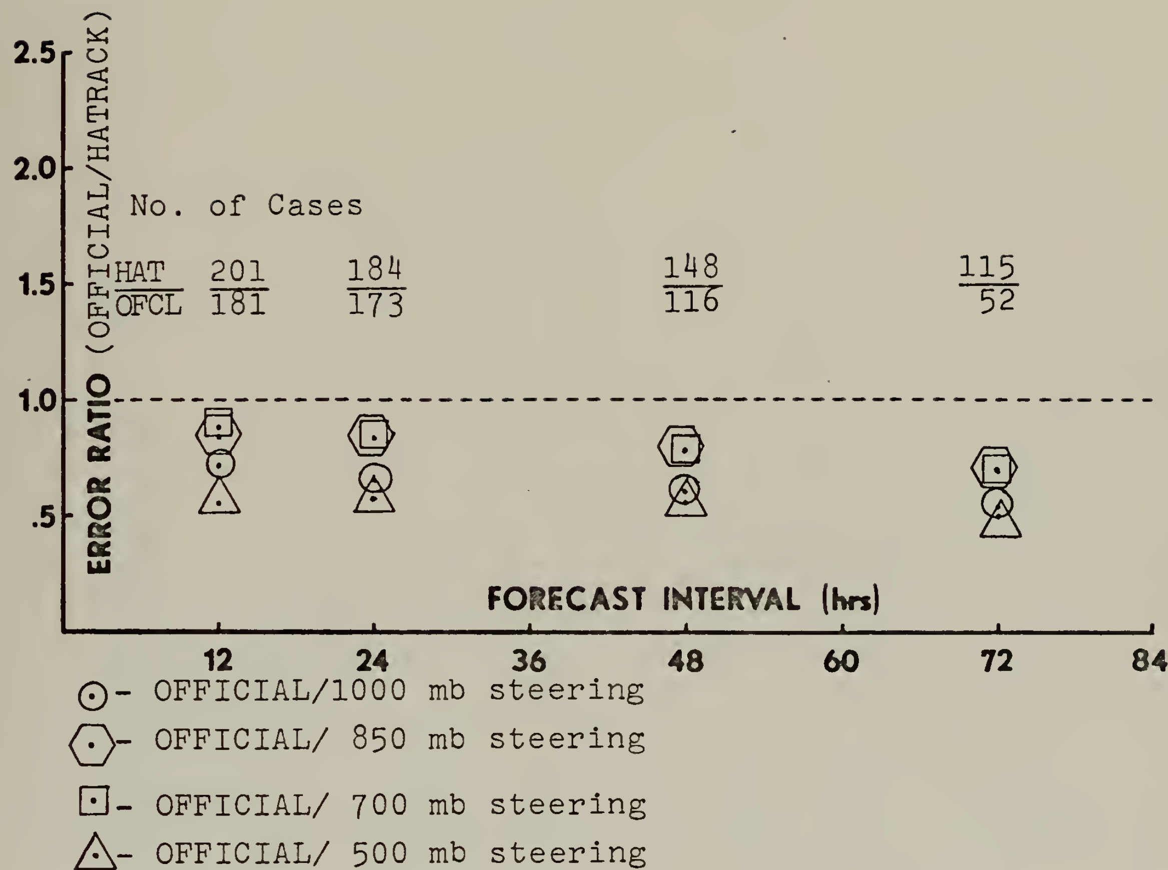


Figure 16 The ratio of OFFICIAL/HATRACK forecast errors, for a non-homogeneous sample, as a function of forecast interval, for the 1971 hurricanes Agatha, Denise, Hilary, Ilsa, Lily, Monica, Nanette, Olivia and Priscilla.

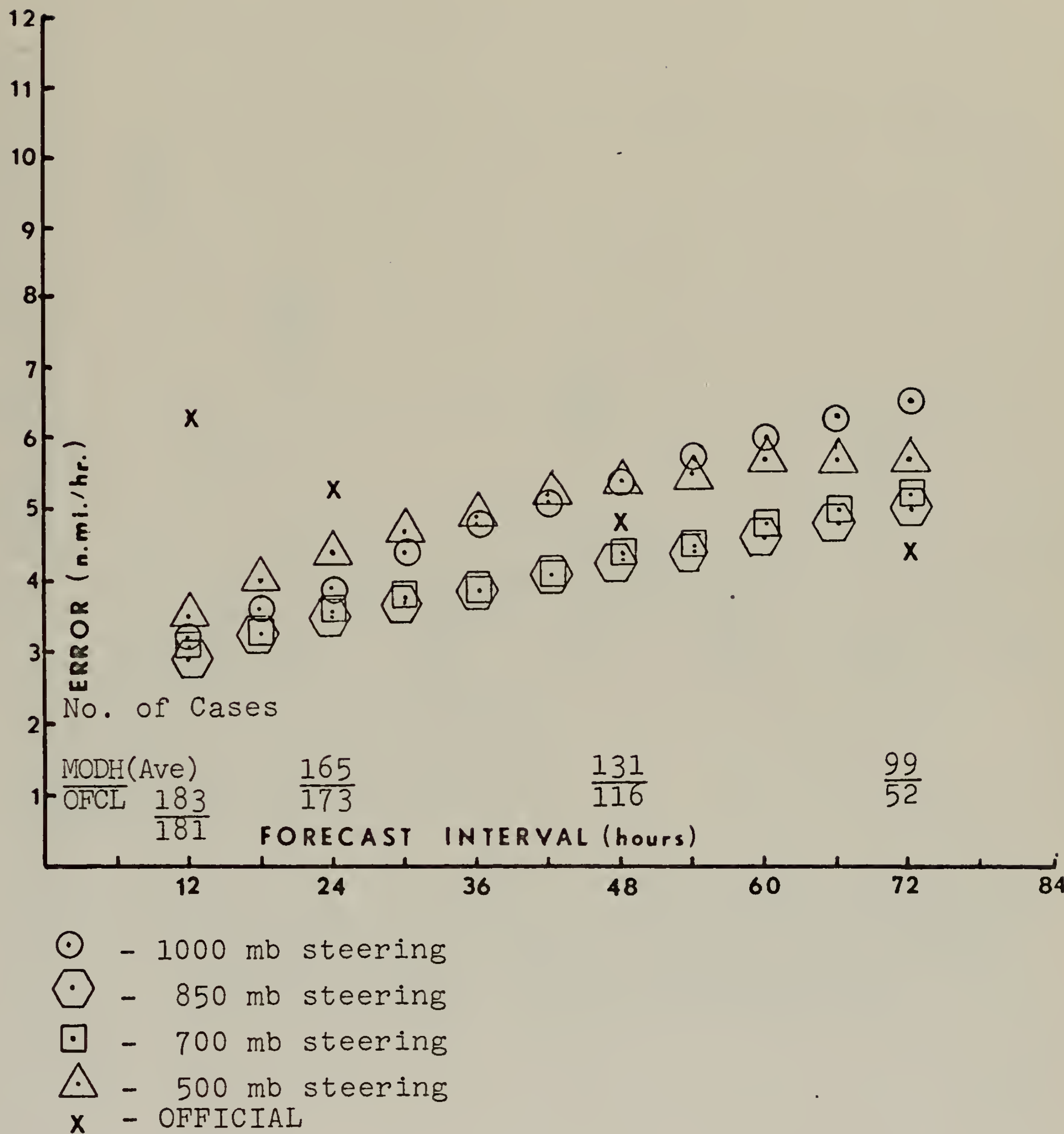


Figure 17 The mean errors of MODHATR (best-track bias) and OFFICIAL, as a function of forecast interval, for 1971 hurricanes Agatha, Denise, Hilary, Ilsa, Lily, Monica, Nanette, Olivia and Priscilla.

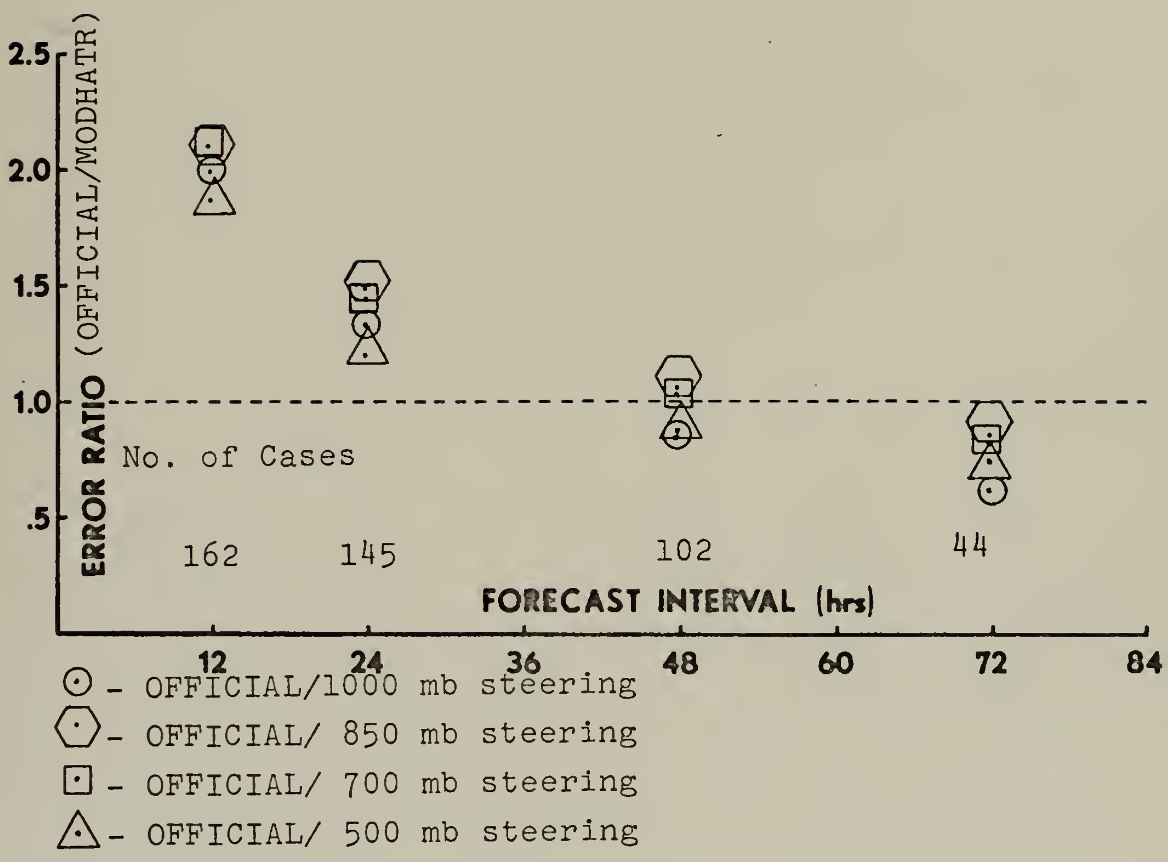


Figure 18 The ratio of OFFICIAL/MODHATR (best-track bias) forecast errors, for a homogeneous sample, as a function of forecast interval, for 1971 hurricanes Agatha, Denise, Hilary, Ilsa, Lily, Monica, Nanette, Olivia and Priscilla.

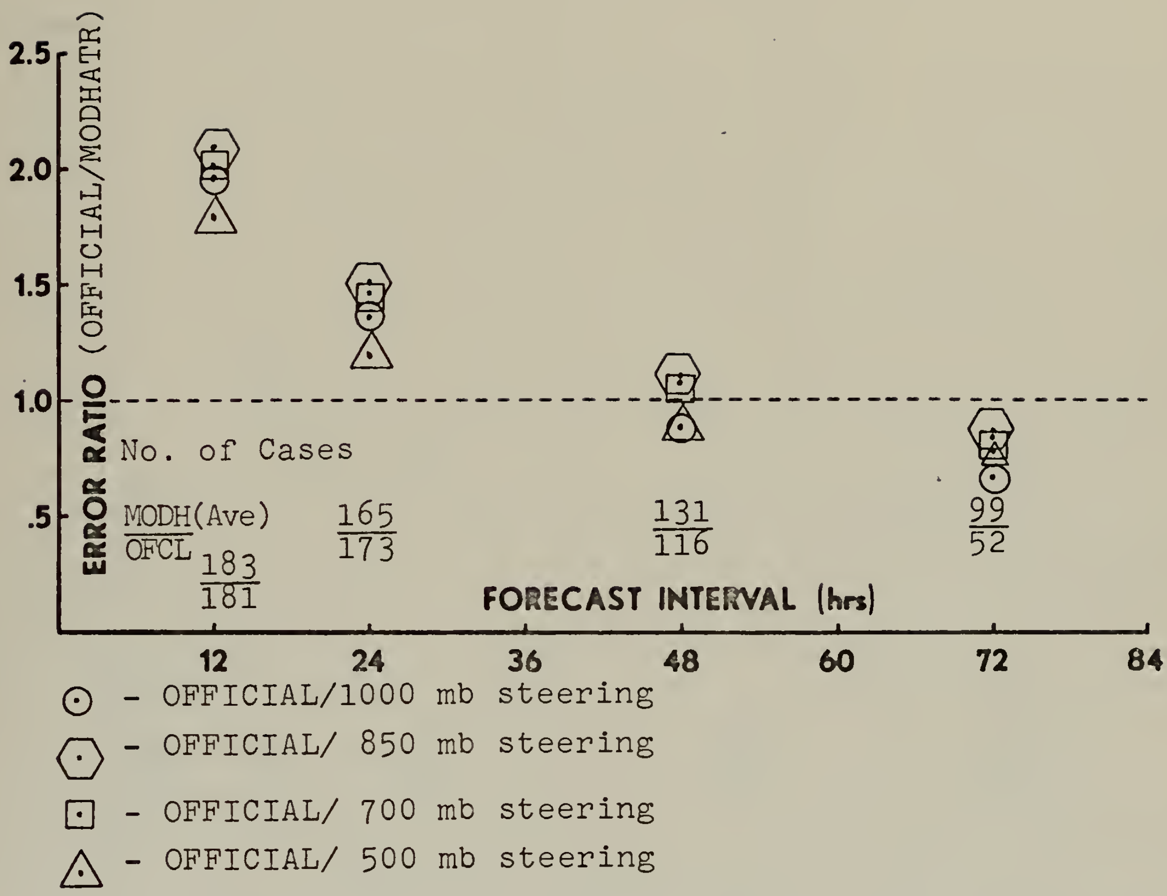
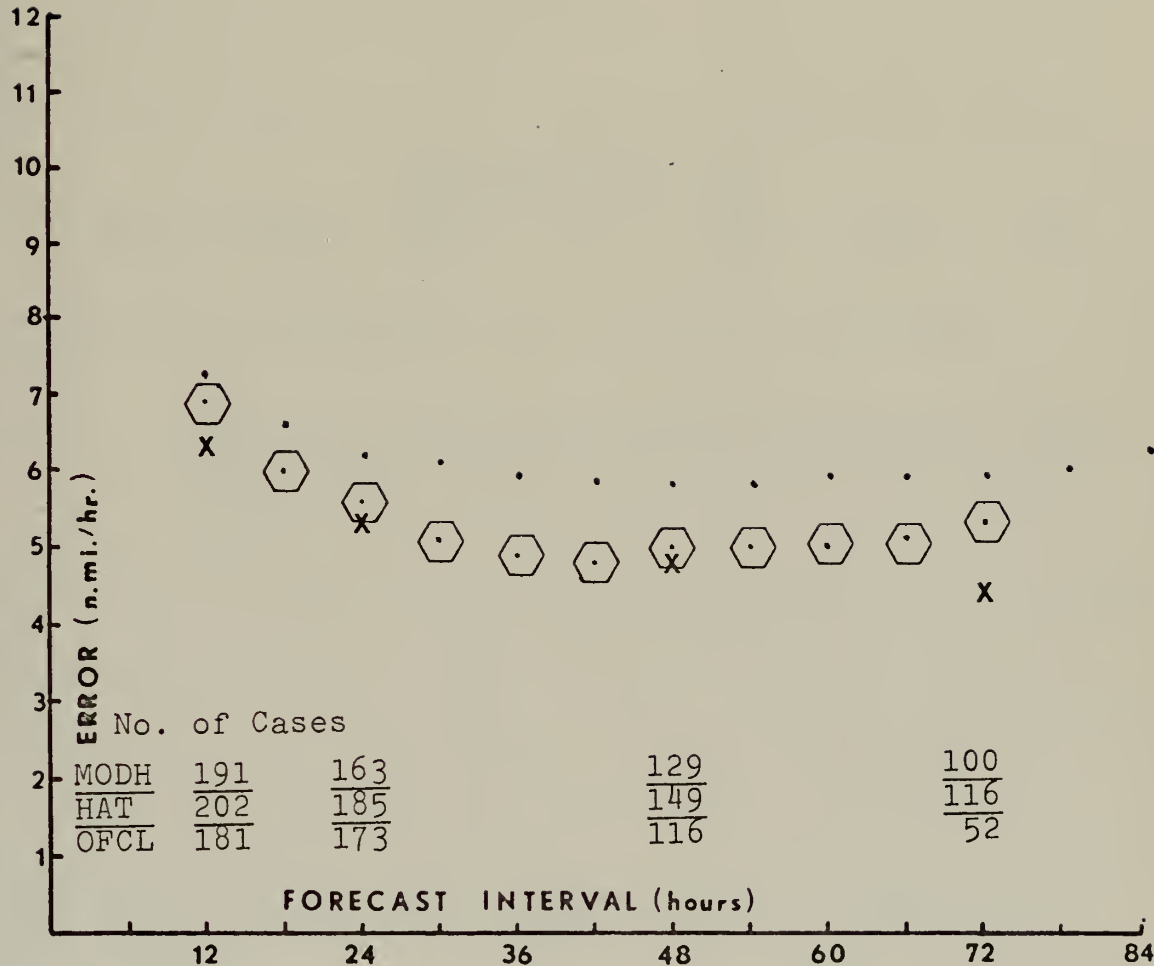


Figure 19 The ratio of OFFICIAL/MODHATR (best-track bias) forecast errors, for a non-homogeneous sample, as a function of forecast interval, for 1971 hurricanes Agatha, Denise, Hilary, Ilsa, Lily, Monica, Nanette, Olivia and Priscilla.

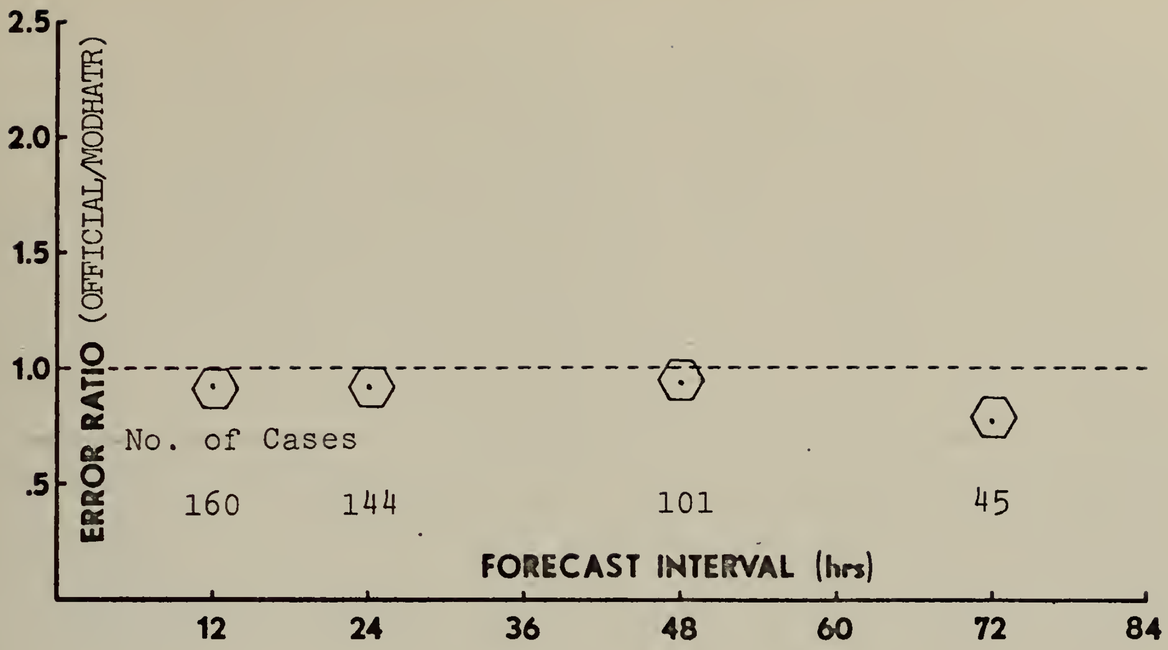


- MODHATR (operational bias) 850 mb steering

X - OFFICIAL

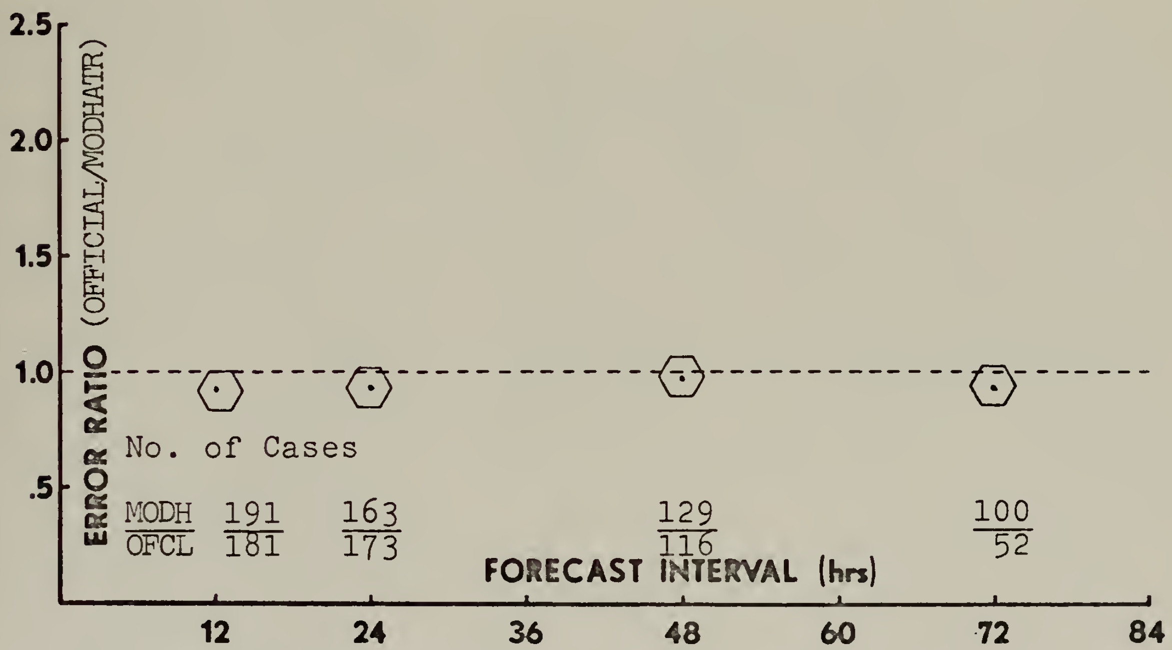
• - HATRACK 850 mb steering

Figure 20 The mean errors of MODHATR (operational bias), HATRACK and OFFICIAL forecasts for the 1971 hurricane sample.



- OFFICIAL/MODHATR Best Level (850 mb) steering

Figure 21 The ratio of OFFICIAL/MODHATR (operational bias) forecast errors, for a homogeneous sample, as a function of forecast interval, for 1971 hurricanes.



- OFFICIAL/MODHATR Best Level (850 mb) steering

Figure 22 Similar to Fig. 21 except for a non-homogeneous sample.

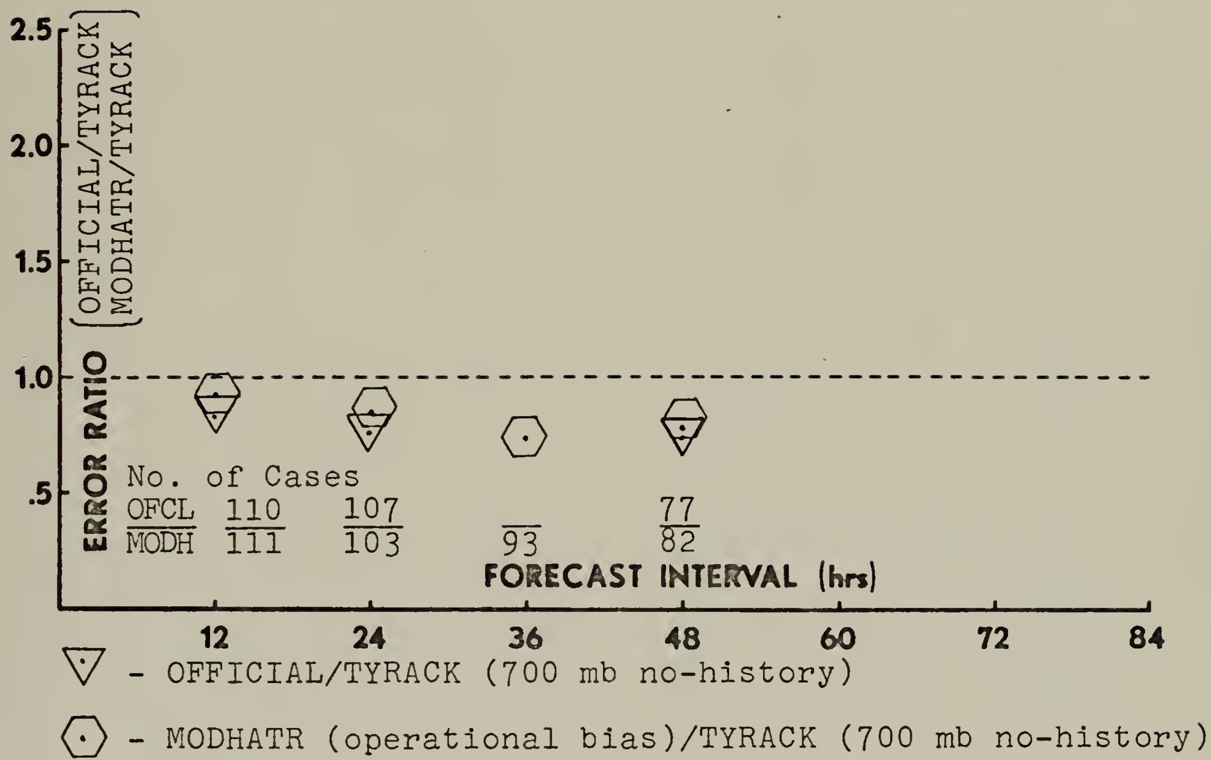


Figure 23 The ratio of OFFICIAL/TYRACK and MODHATR (operational bias)/TYRACK errors as a function of forecast interval for a homogeneous sample of the 1971 hurricanes.

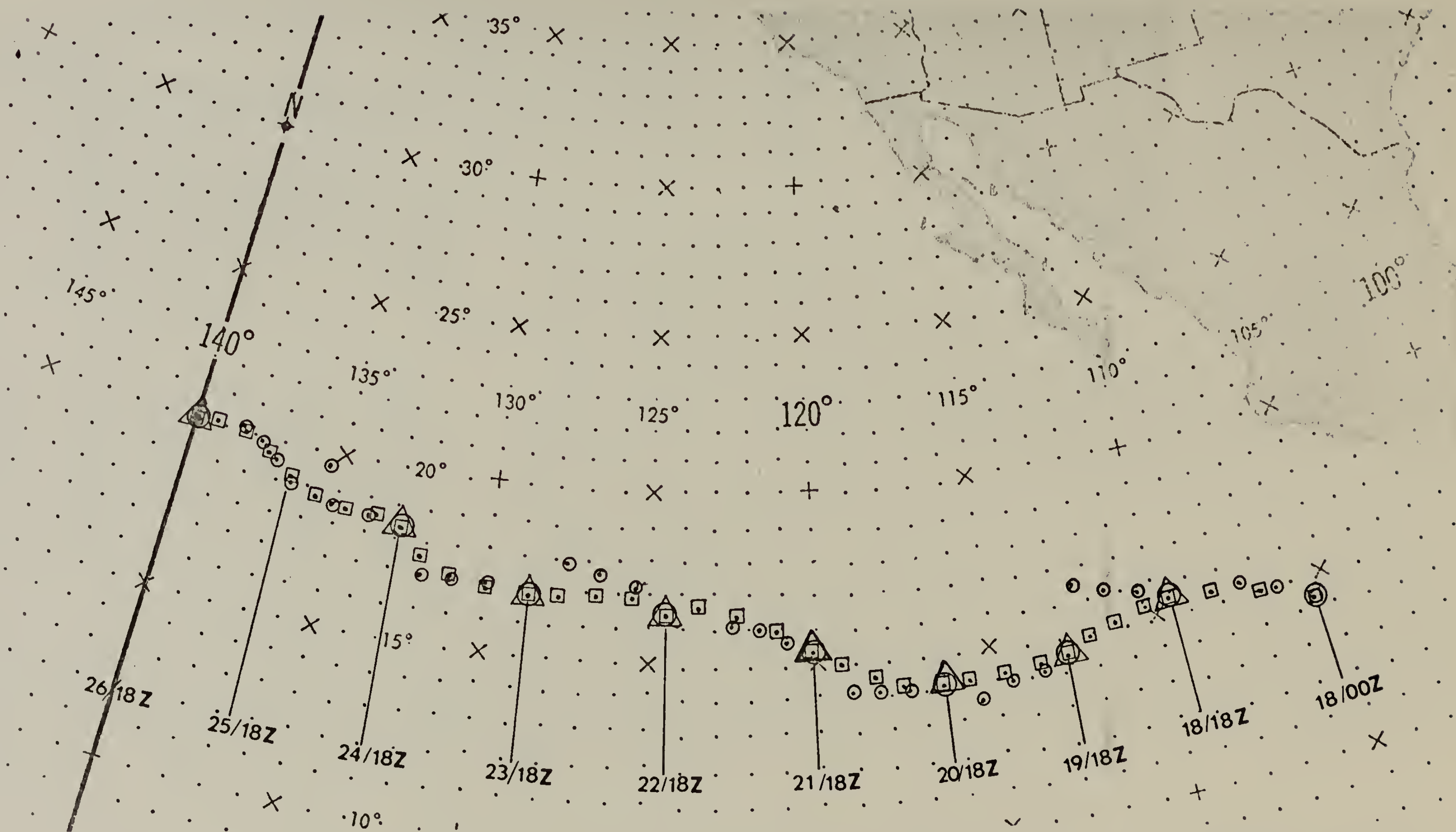


Figure 24 Operational and best-tracks for hurricane Lorraine 1970. ⊙ indicates operational positions, ⊡ denotes best-track positions, aircraft reconnaissance fixes are represented by △.

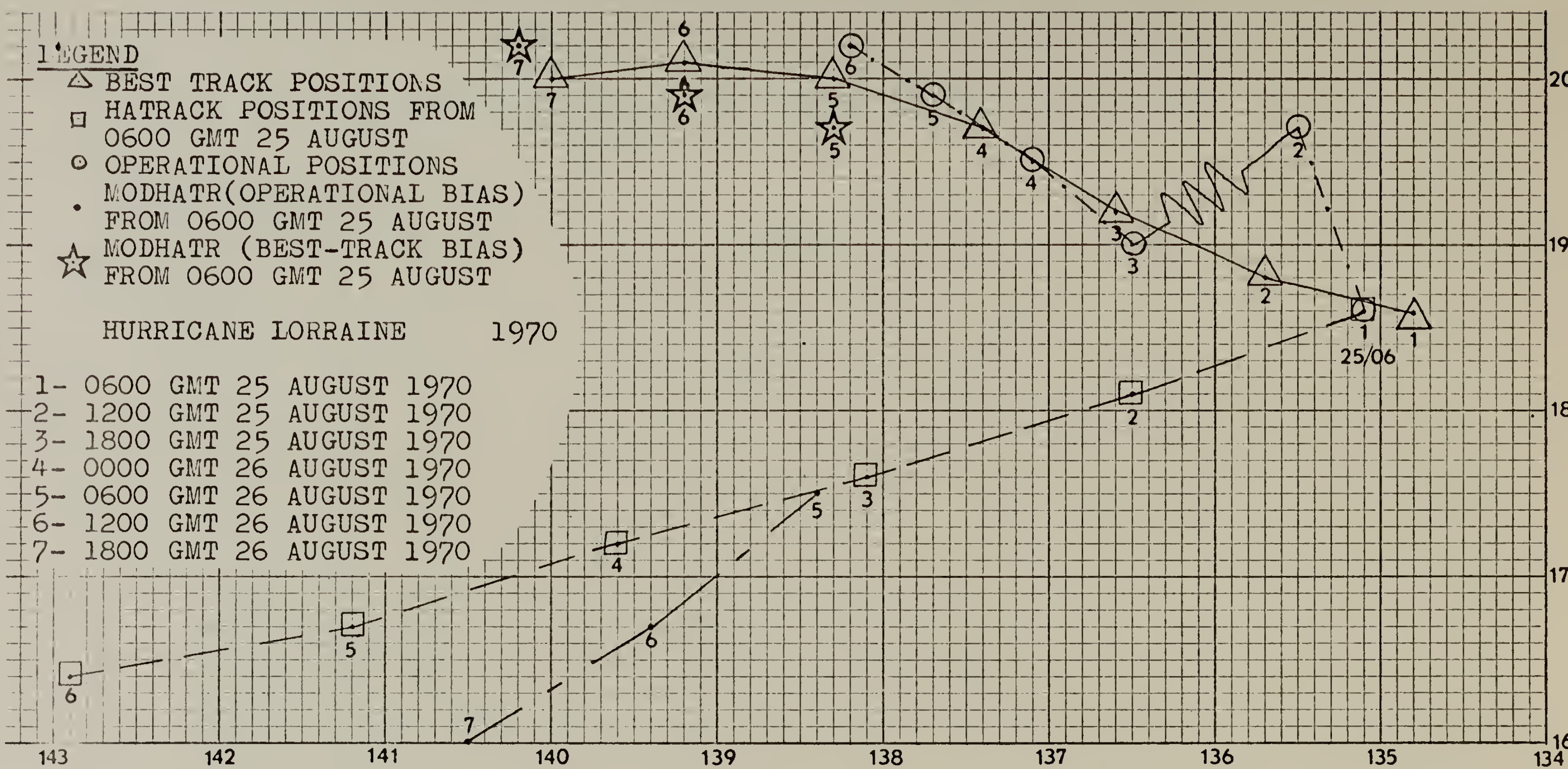
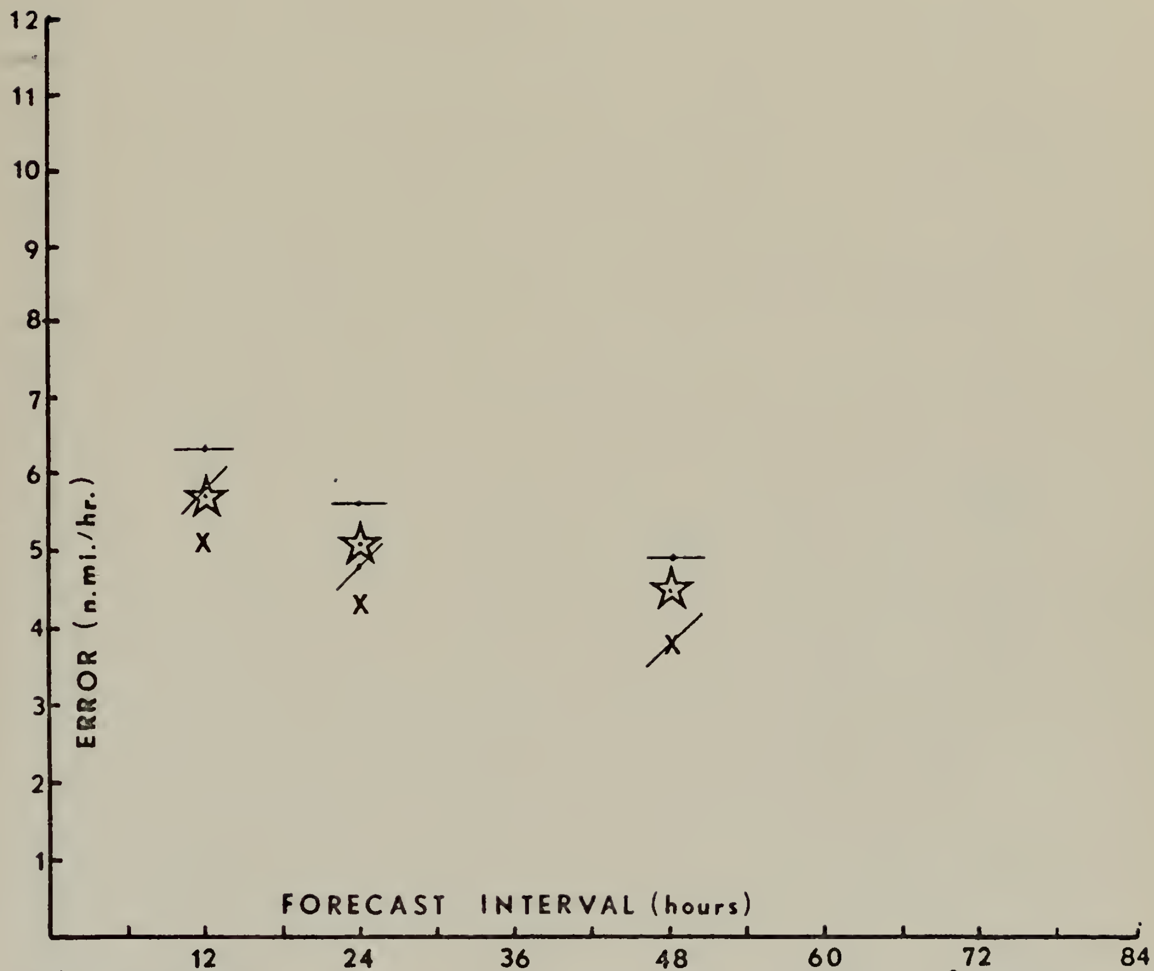


Figure 25 Example of discontinuity in operational track and resulting MODHATR (operational bias) forecasts. The MODHATR (best-track bias) forecasts are presented for comparison.



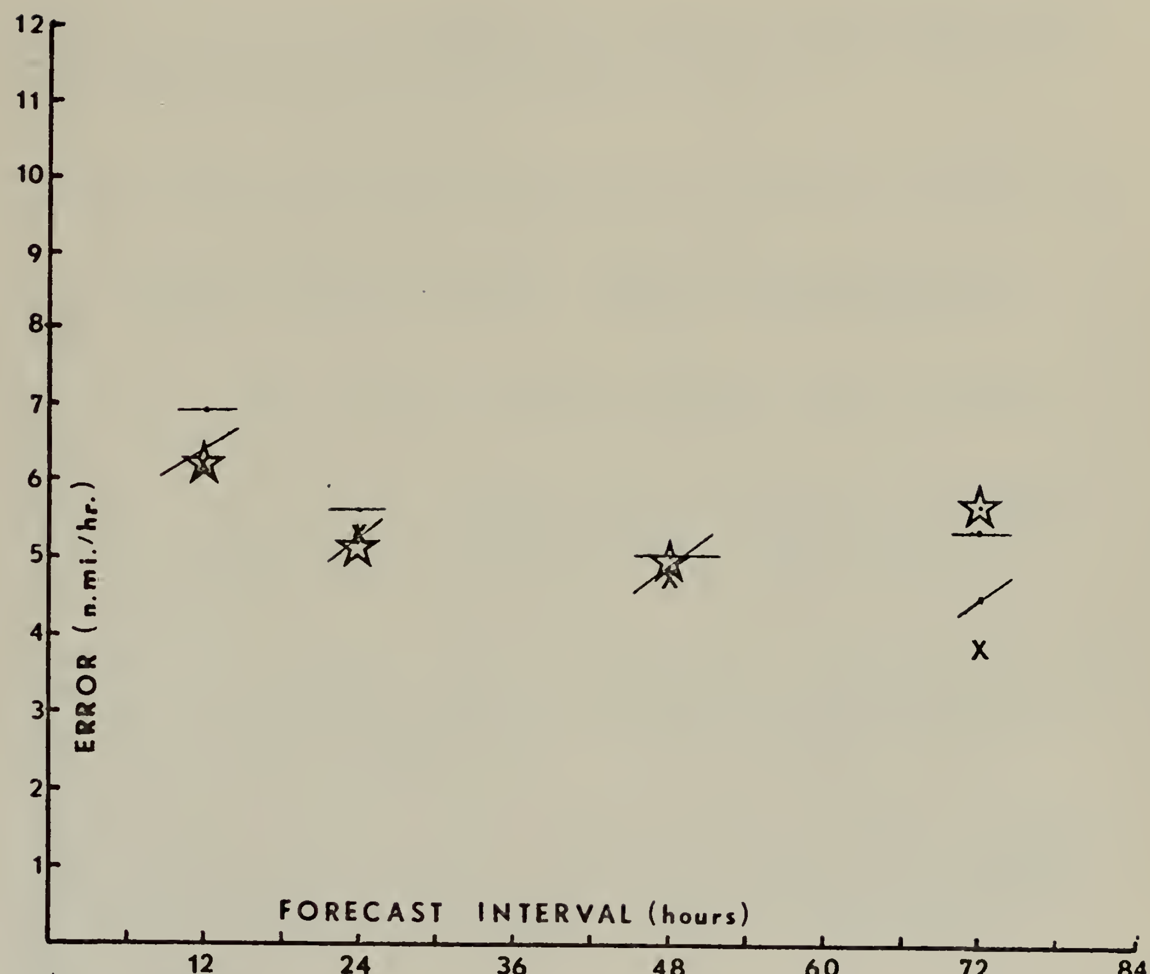
☆ - MODHATR (operational bias) forecasts for 850 mb steering, from 1200 and 1800GMT initial HATRACK times, verifying at same time as OFFICIAL: shown as X.

X - OFFICIAL forecasts, verifying at same time as MODHATR: shown as ☆, from 1200 and 1800GMT

—·— - All MODHATR (operational bias) forecasts based on 850 mb steering

/ - All OFFICIAL forecasts

Figure 26 OFFICIAL and MODHATR (operational bias) forecast errors, 1970.



☆ - MODHATR (operational bias) forecasts for 850 mb steering from 1200 and 1800GMT initial HATRACK times, verifying at same time as OFFICIAL: shown as X.

X - OFFICIAL forecasts verifying at same time as MODHATR HATR: shown as ☆

- All MODHATR (operational bias) forecasts based on 850 mb steering

- All OFFICIAL forecasts

Figure 27 OFFICIAL and MODHATR (operational bias) forecast errors, 1971.

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13. ABSTRACT

Several operational methods of forecasting the motion of tropical cyclones over the northeast Pacific Ocean area are evaluated for three 1970 and nine 1971 hurricanes. OFFICIAL forecast accuracy is shown to excel that of TYRACK (1971 only) and HATRACK (both years). The MODIFIED HATRACK (MODHATR) forecast scheme developed by the Navy in Monterey, California, comprising a numerical steering component (HATRACK) with a statistical modification (correction for bias in HATRACK) is applied to the same 1970-71 operational data, with the result that the MODHATR accuracy, using 850 mb steering, is shown to be superior to HATRACK and TYRACK while only slightly inferior to the OFFICIAL forecasts. Specifically, MODHATR forecast accuracy lies in the range 7 to 5kt for 12 to 72 hour forecasts, respectively, while the ratios of OFFICIAL to MODHATR errors range from 1 to .7 in 1970 for forecasts 12 to 48 hours and from .9 to .8 in 1971 for 12 to 72 hour forecasts, respectively. The number of 1970 forecasts evaluated in the test averaged 35 per forecast interval while the 1971 forecast sample ranged from 160 at 12 hours to 45 at 72 hours.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Hurricanes						
Forecasting						
Eastern Pacific Ocean						
MODIFIED HATRACK						